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South Puget Sound Dissolved Oxygen Study

Interim Nutrient Load Summary for 2006-2007

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Cover photo: Shingle Mill Creek (left) and views of South Puget Sound from ____(center) and from the Barnes Cruise (right)

South Puget Sound
Dissolved Oxygen Study

Interim Nutrient Load Summary

by

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and

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Waterbody Numbers:

WA-09-0010
WA-10-0010,-0020,-0030
WA-13-0010,-0020,-0030
WA-14-0010,-0020,-0050,-0100,-0110,-0120,-0130
WA-15-0010,-0020,-0030,-0040,-0050,-0060,-0070,-0100,-0110,-0120,-0130
WA-PS-0070,-0090,-0240,-0270,-0280,-0290,-0300

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Abstract

Nutrient loads, particularly nitrogen, have been identified as a potential stressor to the Puget Sound ecosystem. One consequence of excessive nutrient loads may be low dissolved oxygen concentrations. Field data have shown that portions of South Puget Sound fall below Washington State water quality standards for dissolved oxygen. In order to understand the underlying dynamics that result in low dissolved oxygen concentrations, the Washington State Department of Ecology has initiated a study to identify nutrient loads to South Puget Sound and develop a hydrodynamic and water quality model to assess alternative management scenarios.

As part of this effort, water quality data were collected from July 2006 through October 2007 from a number of wastewater treatment plants (WWTPs), rivers and streams within South and Central Puget Sound. These field data, however, were collected at monthly intervals. A statistical method called multiple linear regression was applied to the field data to develop continuous *daily* loads of nutrients into South and Central Puget Sound for the years 2006 and 2007. This statistical approach relates concentrations to seasons of the year and flow patterns using a best fit to monitoring data. The resulting daily loads provide a better fit to monitoring data than simply using monthly or annual averages.

This report presents the results of this effort and describes the magnitudes and sources of nitrogen loading into South and Central Puget Sound. Rivers and WWTPs are both significant sources of nitrogen, particularly dissolved inorganic nitrogen (DIN; sum of ammonium and nitrate + nitrite). WWTP DIN concentrations and loads are generally greater than those from rivers. In comparison, DIN loads from the atmosphere are significantly lower in magnitude, contributing to 1% of the total annual DIN load. DIN loads from Central Puget Sound (north of Tacoma Narrows) are about three and a half times greater than those from South Puget Sound.

Acknowledgements

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  - Pat Coxon (Bremerton), Ralph Declements (Central Kitsap)
  - Jim Fleming (Lakota, Redondo)
  - John Gardner (Suquamish)
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  - Rob Koden (Seashore Villa)
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  - Dave Hallock and Bill Ward performed supplemental freshwater monitoring

The South Puget Sound Dissolved Oxygen Study Advisory Committee reviewed the document.

Executive Summary

Introduction

Portions of South Puget Sound have low dissolved oxygen (DO) levels that fall below Washington State water quality standards. Low DO levels impair the ability of marine life to survive or thrive, and can affect the healthy functioning of the Puget Sound ecosystem. DO levels decrease when significant quantities of nitrogen enter Puget Sound and stimulate extensive algae growth. When these algae bloom and die-off, the decomposition process uses up DO in the bottom waters, decreasing DO levels.

The Washington State Department of Ecology initiated the South Puget Sound Dissolved Oxygen Study to determine the extent of low DO levels and understand how nitrogen from a variety of sources affects DO levels. The study began with field data collection between July 2006 and October 2007 to support the development of hydrodynamic and water quality models. The results of the field data were published in the Interim Data Report (Roberts et al., 2008). Ongoing modeling efforts will show if human-related sources of nitrogen need to be reduced to protect water quality. The modeling will also be used to assess alternative management scenarios. Information on the South Puget Sound Dissolved Oxygen Study is available at www.ecy.wa.gov/puget_sound/dissolved_oxygen_study.html. The study focuses on South Puget Sound, south of Tacoma Narrows. However, since nitrogen loads from Central Puget Sound (between Tacoma Narrows and Edmonds) may influence South Puget Sound water quality, the entire South and Central Sound are included in the study (Figure ES-1).

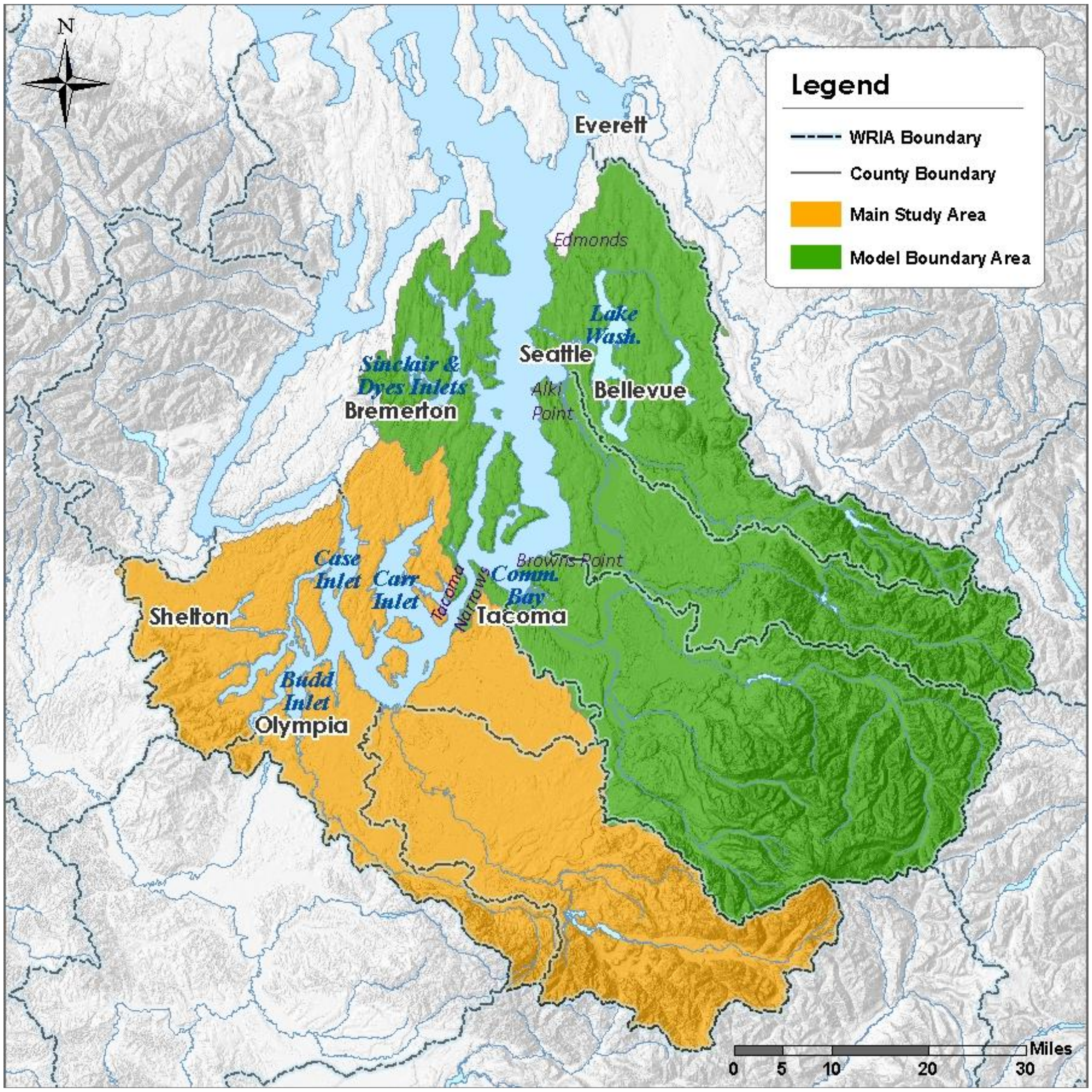

Figure ES-1. Study area for the South Puget Sound Dissolved Oxygen Study.

Methods

Although nutrient data collected from rivers and WWTPs that discharge directly to Puget Sound were already summarized in the Interim Data Report, these data were collected at a *monthly* interval. The models being used, however, require *daily* data on flows and nutrient loads into South and Central Puget Sound to simulate seasonal and sub-seasonal variations in South Puget Sound.

This report specifically describes the development of daily nutrient loading estimates from the monthly field monitoring data. A multiple linear regression method was applied to the field data to develop continuous daily concentrations and loads of nutrients for calendar years 2006 and 2007. This method relates concentrations to flow and time of year using a best fit to monitoring data. The resulting daily loads provide a better fit to monitoring data than simply using monthly or annual averages.

Overall, 82% of the total study area (both South and Central Puget Sound) was included in monitored watersheds, and 89% of all the WWTP discharges (in terms of the magnitude of effluent flow) were monitored. The regression-derived estimates compared relatively well with the field data and were also used to estimate loads from watersheds and WWTPs that were not monitored at all, or only monitored briefly.

Continuous daily nutrient load data are not only needed for the calibration and validation of the hydrodynamic and water quality model, but also provide us with a more comprehensive understanding of nutrient loads. The development of daily nutrient data allows us to quantify the relative magnitude of nutrient loads from rivers and WWTPs, describe the seasonal nature of these loads, and compare loads between Central Puget Sound and South Puget Sound.

This report primarily focuses on and presents nitrogen load summaries from rivers, WWTPs and on-site septic systems. However, in addition to these sources of nitrogen, the water quality model will also include nitrogen loading from the ocean, the atmosphere and internal sediment fluxes. This will allow us to analyze the effect of all these sources on DO levels.

In addition to estimating nutrient concentrations and loads for 2006-2007, we also calculated natural (i.e. no human influence) nutrient concentrations and loads for inflows into South and Central Puget Sound. Natural conditions in this study refer to the concentrations of nutrients in rivers and streams before significant human influences/sources of nutrients existed. By definition, there would be no WWTP or septic system inputs into Puget Sound under natural conditions. Once these concentrations are established, they can be used as inputs into the water quality model so that we can evaluate the water quality of Puget Sound under natural conditions.

The natural condition was established from the results of a meta-analysis where we used concentration data from various sources: historic and current ambient monitoring data, rainfall data, and data from other studies. The median value from these various methods was then used to calculate the natural condition.

Results and Discussion

Of all the forms of nitrogen, dissolved inorganic nitrogen (DIN; sum of nitrate+ nitrite and ammonium) is of greatest interest. Figure ES-2 compares median DIN concentrations in rivers and WWTPs discharging directly into South and Central Puget Sound during 2006 and 2007. River DIN loads include all point and non-point sources that discharge into these rivers. For example, the Puyallup WWTP is a point source which discharges into the Puyallup River and is therefore included in the Puyallup River load.

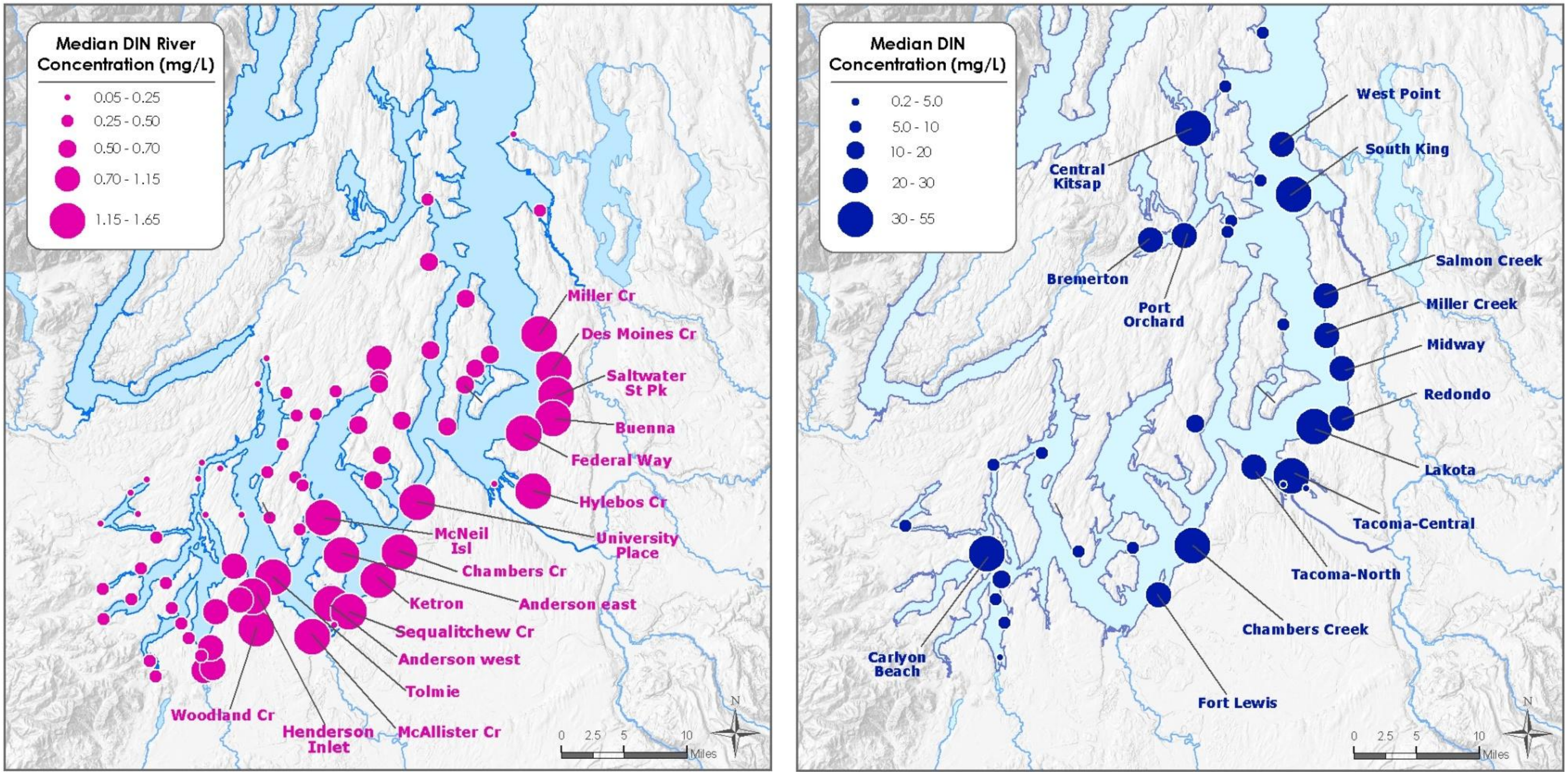

Figure ES-2. Median river (left) and WWTP (right) dissolved inorganic nitrogen concentrations for 2006 through 2007.

Rivers and WWTPs with the highest DIN concentrations are not necessarily the same ones that also have the highest DIN loads. Since loads are calculated as the product of concentration and flow, rivers and WWTPs with higher flows tend to have the larger loads.

Annual loads from rivers and streams are relatively low, but dominated loading in many of the western inlets in South Puget Sound, including Totten, Eld, Henderson, Case, and Carr Inlets (Figure ES-3). The rivers with the largest loads are, in order, the Puyallup, Green, Nisqually, and Deschutes Rivers, which together contribute an annual DIN load of 7100 kg/d. In Central Puget Sound, WWTP loads dominate because there are a larger number of WWTPs serving larger populations than in South Puget Sound. West Point and South King WWTPs are the two greatest sources, together contributing 18,500 kg/d, which is more than twice the load of the four rivers with the highest load.

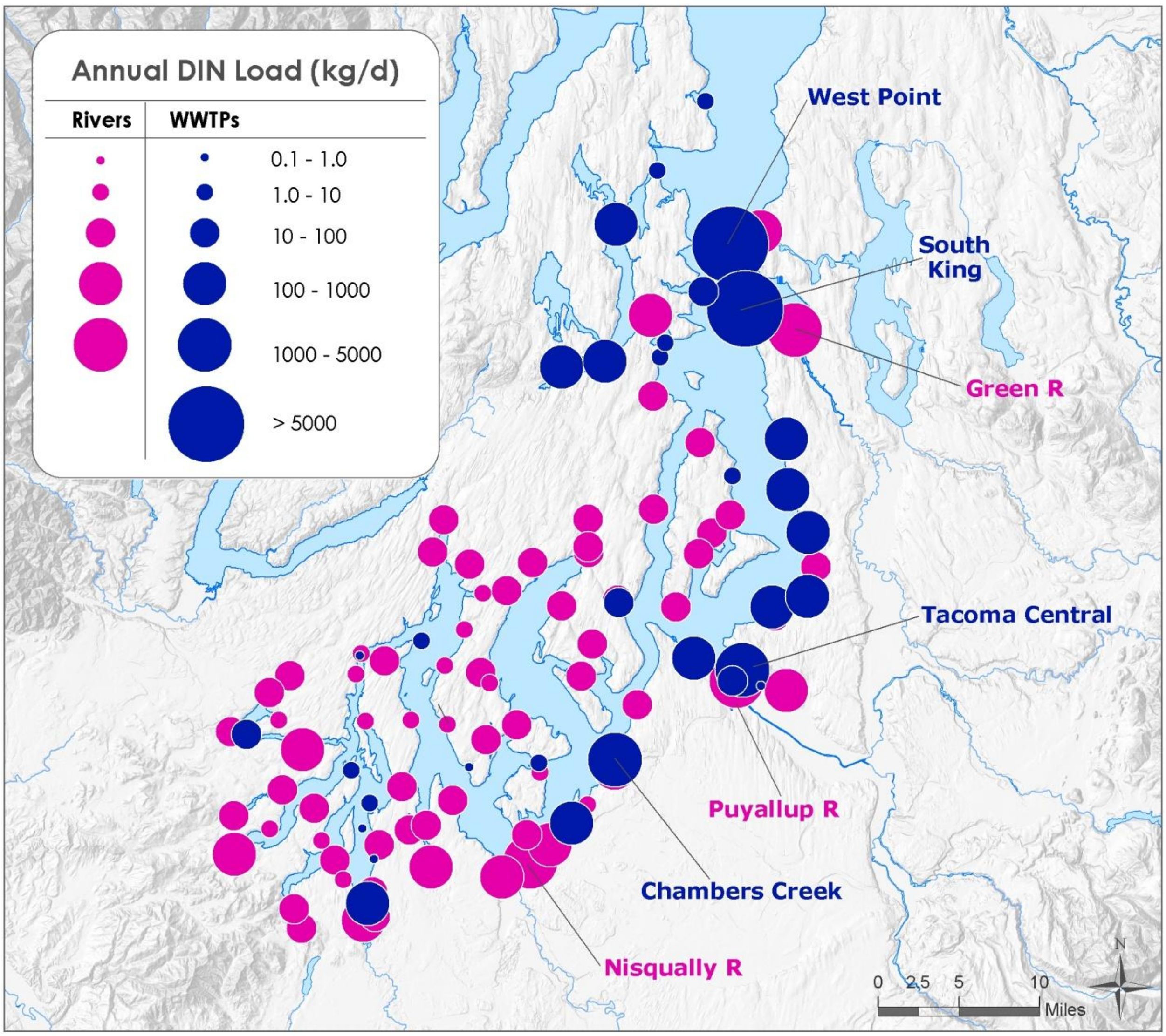

Figure ES-3. Mean annual dissolved inorganic nitrogen loads from rivers and WWTPs in South and Central Puget Sound from 2006-2007.

DIN loads from WWTPs also dominate in the summer (average of July, August and September), which is a critical time for dissolved oxygen conditions (Figure ES-4). During this time, river loads are lower because of lower flows.

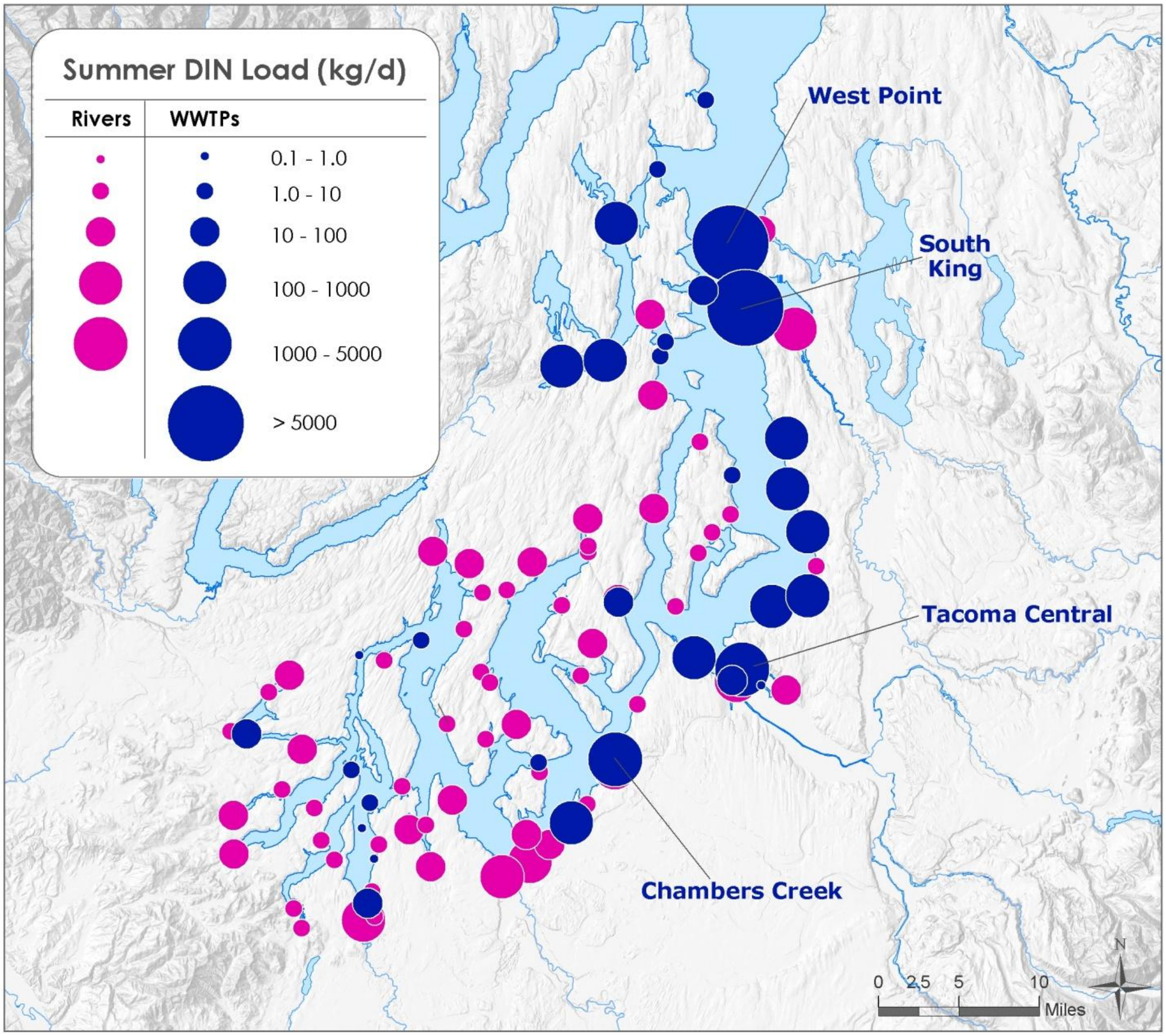

Figure ES-4. Mean summer DIN loads from rivers and WWTPs in South and Central Puget Sound from 2006-2007.

Loads from WWTPs are also less variable throughout the year, while those from rivers respond more strongly to seasons due to changes in precipitation and flow. Daily loads from Central Puget Sound are consistently greater than those from South Puget Sound (Figure ES-5). WWTPs contribute 59% of the total DIN load during the winter months (November through March), and 90% of the total DIN load during the summer months (July through September, Figure ES-5).

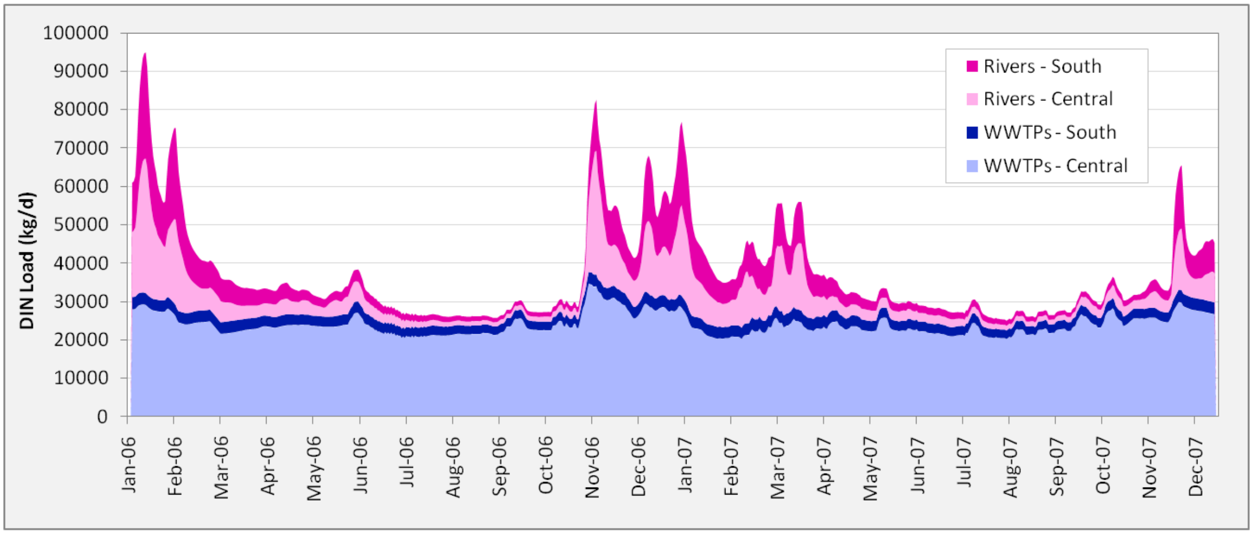

Figure ES-5. Seven-day average of daily DIN loads from rivers and WWTPs in South and Central Puget Sound during 2006-2007.

In South Puget Sound, rivers contribute 65% the total DIN load on an annual basis. During the summer, however, when river loads are significantly lower, rivers contribute 37%, while WWTPs contribute 63% of the total DIN load (Figure ES-6, top).

In Central Puget Sound, WWTP loads dominate regardless of the time period of analysis, contributing 81% of the total DIN load on an annual basis, 94% of the total DIN load during the summer (Figure ES-6, center).

When loads from South and Central Puget Sound are combined, WWTPs still dominate, contributing to 71% of total DIN load on an annual basis and to 90% of the total DIN load during the summer months.

Rivers contribute comparable annual DIN loads to South and Central Puget Sound: 5080 kg/d to South Puget Sound, and 5810 kg/d to Central Puget Sound. WWTPs contributions, however, vary greatly between South and Central Puget Sound: 2700 kg/d to South Puget Sound, and 24,050 kg/d to Central Puget Sound. The WWTPs in Central Puget Sound serve higher population centers and therefore treat and discharge a much larger volume of wastewater than those in South Puget Sound.

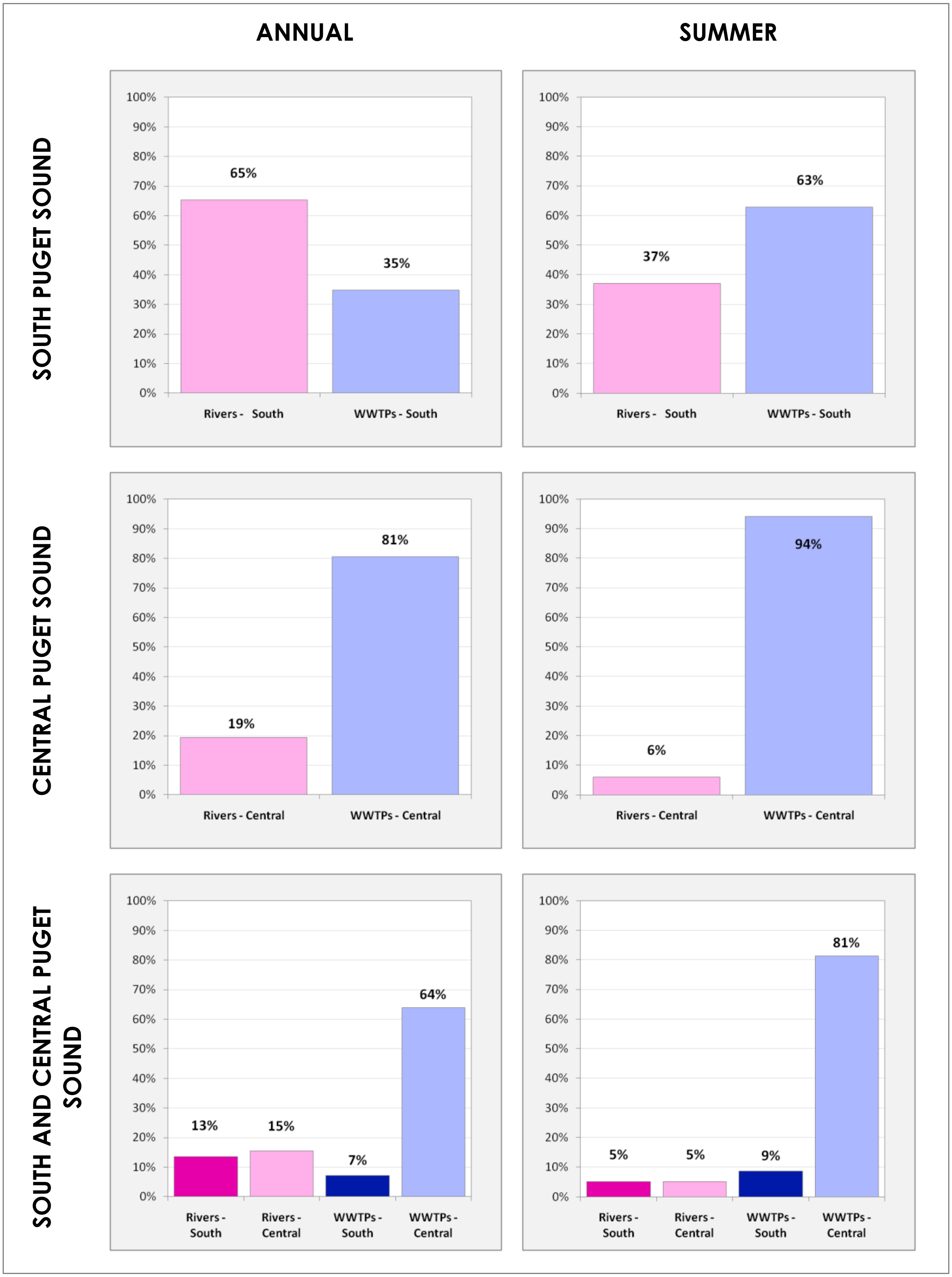

Figure ES-6. Pie charts comparing the relative contributions of DIN loads from rivers and WWTPs in South and Central Puget Sound on an annual basis (2006-2007) and during the summer.

Overall, DIN loads from Central Puget Sound are 3.8 times greater than DIN loads from South Puget Sound (Figure ES-7).

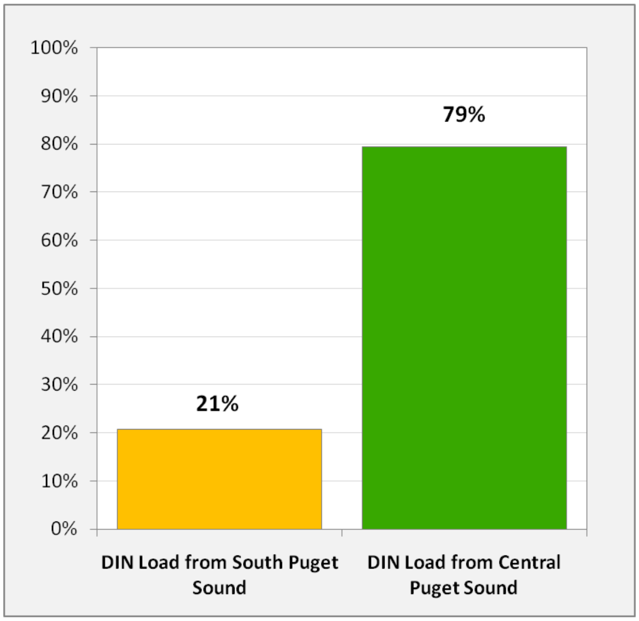

Figure ES-7. Annual dissolved inorganic nitrogen loads from rivers and WWTPs in South vs. Central Puget Sound.

When we include the DIN load from atmospheric deposition, we see that this contributes only 1% of the total DIN load (Figure ES-8).

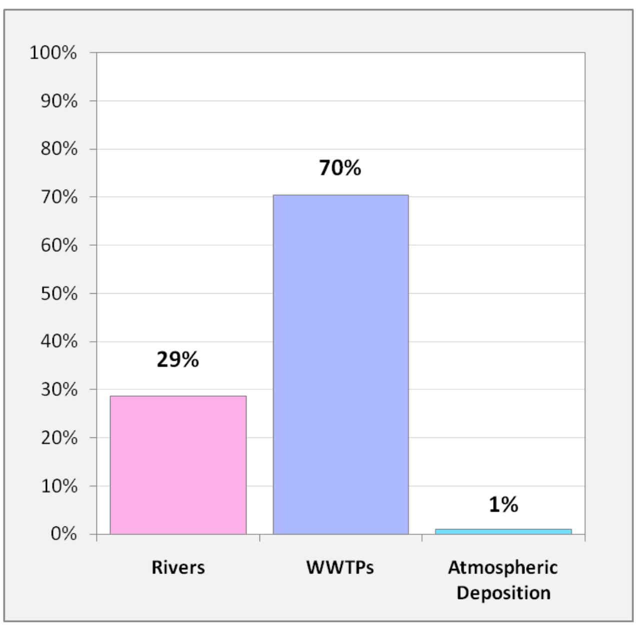

Figure ES-8. Annual dissolved inorganic nitrogen loads from rivers, WWTPs and the atmosphere in South and Central Puget Sound.

Table E-1 compares annual average DIN loads from 2006-2007 with natural DIN loads based on our calculation of natural conditions.

Table E-1. Comparison of natural and 2006-2007 average annual DIN loads from rivers and WWTPs discharging into South and Central Puget Sound.

	Average Annual DIN Load (kg/d)		
	Natural Conditions	2006-2007 Rivers Only	2006-2007 Rivers + WWTPs
South Puget Sound	1410	5080	7785
Central Puget Sound	2415	5810	29860
South + Central Puget Sound	3825	10890	37645

Current nutrient loads from rivers and streams, which include wastewater treatment plants discharging to freshwater, are 2.8 times natural condition loads to South and Central Puget Sound. When we include rivers and all WWTPs, including those discharging to marine waters, current loads are 10 times natural condition loads. The difference between current and natural loads reflects the influence of anthropogenic sources of nutrients, including changes in land use and development, increases in population, and loads from WWTPs.

Conclusions

We now have comprehensive daily estimates of nutrient loads, which we can use to better understand the magnitudes and sources of nitrogen loading into South and Central Puget Sound. We can now also describe how the relative contributions of DIN loads change over the course of the year and for different regions in the study area.

The water quality modeling effort will be key in identifying how sensitive DO levels in South Puget Sound are to the higher loads coming from Central Puget Sound by analyzing how nutrients circulate once they enter Puget Sound. We recommend that these nutrient loading data be used as part of the water quality modeling effort. If certain watersheds or WWTPs where we did not collect data appear to have a large influence on DO levels, it will be important to collect data for these specific locations.

With this data, the water quality model will also allows us to assess alternative management scenarios by changing the magnitude of DIN loads from particular sources, and evaluate how effective these changes might be in improving DO levels in South Puget Sound.

Introduction

This report is part of a larger multi-year study focused on investigating the water quality of South Puget Sound. The Washington State Department of Ecology (Ecology) initiated the study to understand the behavior of South Puget Sound under current and future conditions based on water quality monitoring as well as hydrodynamic and water quality modeling.

The study was designed to determine whether point and non-point source nutrient loadings contribute to low dissolved oxygen (DO) concentrations in South Puget Sound. Dissolved oxygen levels that fall below Washington State Water Quality Standards have been observed in several parts of South Puget Sound. Dissolved oxygen levels decrease when excess nutrients, particularly nitrogen, enter Puget Sound, stimulating algae growth. These algae subsequently die-off and decompose – a process which consumes DO. Low DO levels can be harmful to fish and other marine life, raising concerns about the health of the Puget Sound ecosystem. Figure 1 illustrates how areas of South Puget Sound, including Budd, Carr, and Case Inlets, are of concern due to low DO concentrations.

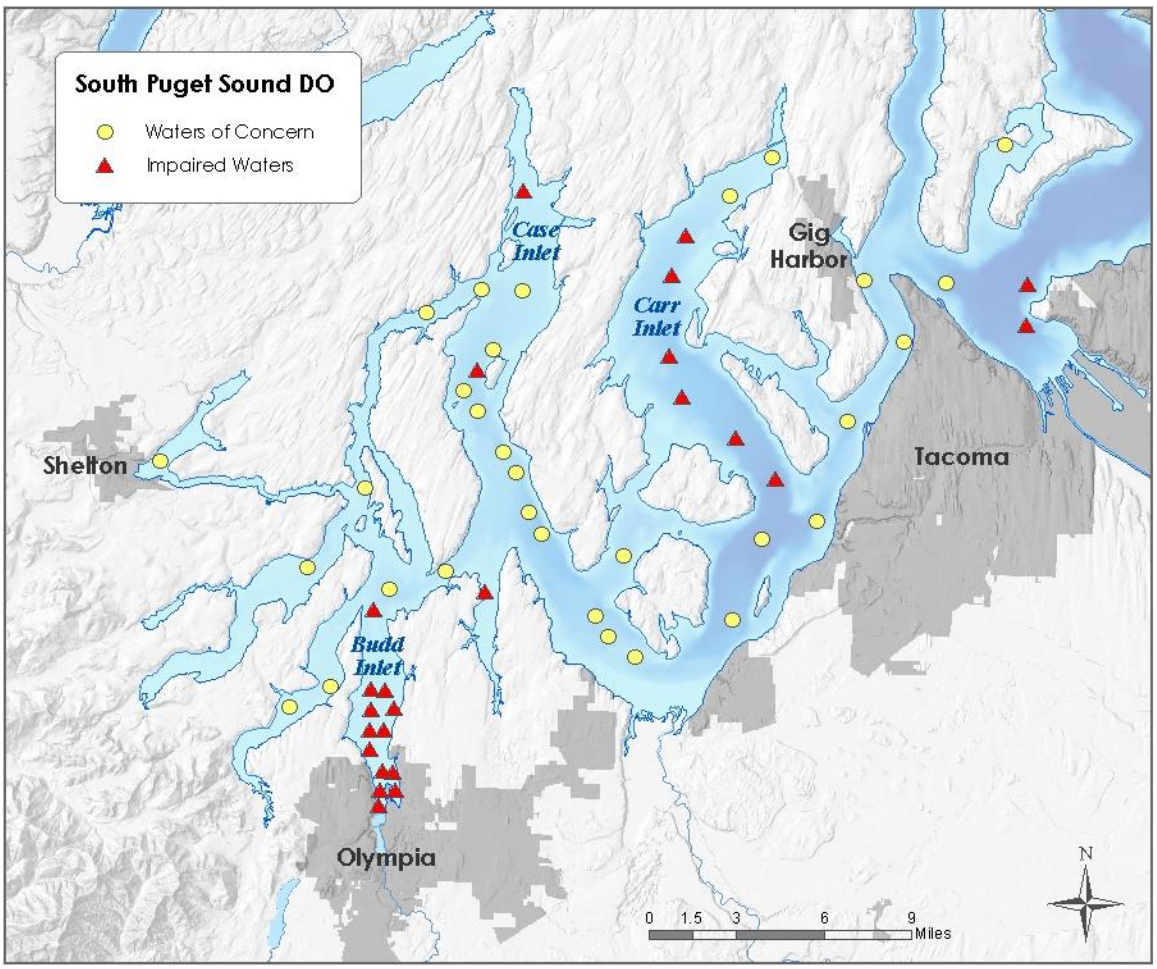

Figure 1. Results from the 2008 Water Quality Assessment for dissolved oxygen in South Puget Sound.

The purpose of the South Puget Sound Dissolved Oxygen Study is to determine how nutrients from a variety of sources affect DO levels in South Puget Sound, which is defined as the area south of the Tacoma Narrows (Figure 2) and the watersheds that drain into these marine waters.

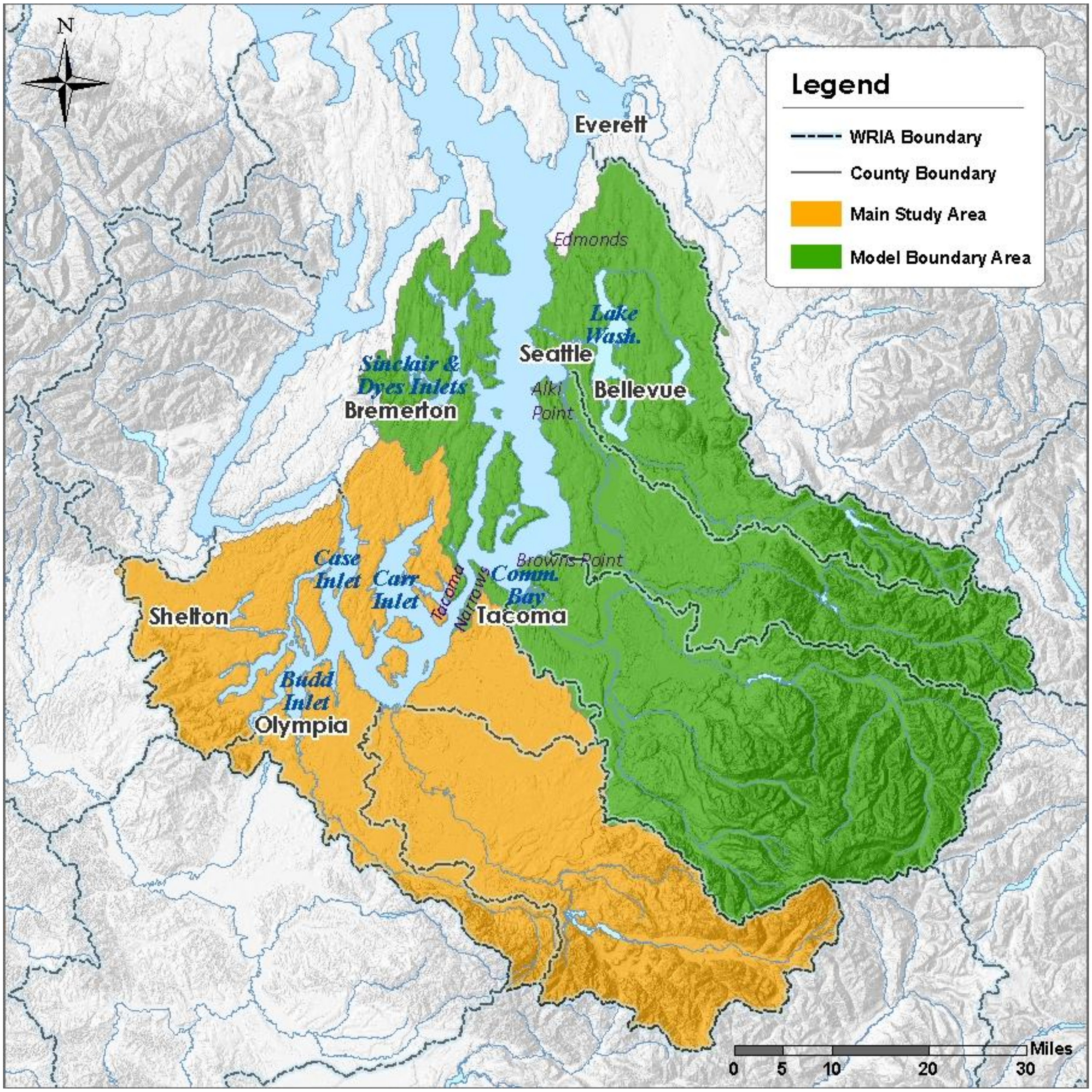

Figure 2. Study area for the South Puget Sound Dissolved Oxygen Study.

Even though South Puget Sound is the primary focus of the South Puget Sound Dissolved Oxygen Study, the model boundary extends further north to also include the marine waters of *Central* Puget Sound. This is because the more highly populated watersheds that drain into Central Puget Sound contribute higher nutrient loads and may also potentially impact South Puget Sound water quality. Table 1 compares the characteristics of South and Central Puget

Sound. The population density in Central Puget Sound is more than twice that of South Puget Sound.

Table 1. Characteristics of the study area for the South Puget Sound Dissolved Oxygen Study.

	South Puget Sound	Central Puget Sound	Full Study Area
Land Area	4,290 km^2 (1,660 mi^2)	6,420 km^2 (2,480 mi^2)	10,710 km^2 (4,140 mi^2)
Marine Water Area	425 km^2 (165 mi^2)	630 km^2 (245 mi^2)	1055 km^2 (410 mi^2)
Population*	661,700	2,307,200	2,968,900
Population Density	155 people/km^2	360 people/km^2	280 people/km^2

*2001 census block population data from the Office of Financial Management

The South Puget Sound Dissolved Oxygen Study was initiated with a large field data collection effort from July 2006 through October 2007. The field effort included the measurement of various water quality parameters within South Puget Sound as well as monthly grab samples from rivers, streams, and wastewater treatment plants (WWTPs) that drain or discharge into South or Central Puget Sound. The experimental design for this is described in detail in the Quality Assurance (QA) Project Plan (Albertson, et al., 2007), and the results from this field data collection effort were subsequently presented and published in an Interim Data Report (Roberts, et al., 2008).

The data from the monitoring effort is being used to model South and Central Puget Sound using the Generalized Environmental Modeling System for Surface Waters (GEMSS), a three0dimensional hydrodynamics and water quality model. This model will be used to characterize and evaluate nutrient loads into South and Central Puget Sound.

GEMSS requires daily time series of flows and nutrient loads from discrete watershed inflow points to simulate seasonal and sub-seasonal variations in South Puget Sound. Water quality parameters required by the model include various forms of nitrogen, phosphorus, and carbon. This report specifically describes the development of *daily* nutrient loading data from the *monthly* field monitoring data and describes the results of this process in the context of nutrient loading into South and Central Puget Sound. A statistical method called multiple linear regression was applied to the field data to develop continuous daily loads of nutrients for the calendar years 2006 and 2007.

Continuous daily nutrient load data are not only needed for the calibration and validation of the hydrodynamic and water quality model being developed, but also to provide a more comprehensive understanding of nutrient loads. The development of daily nutrient data also allows us to quantify the relative magnitude of nutrient loads from rivers and WWTPs, describe the seasonal nature of these loads, and compare Central Puget Sound to South Puget Sound load.

On-site septic systems along the shoreline fringe are another source of nutrient loading. Since monitoring locations were not always located directly at the mouth of each river or stream, extrapolation of monitoring locations to the mouth may not accurately capture loading from the from on-site septic systems if there are a high number of these in shoreline fringe than within the monitored areas. The monitoring program captured 82% of the watershed contributions (in terms of area) to South and Central Puget Sound, and loads from monitored areas include on-site septic system loads upstream of monitoring locations.

Load data from monitored watersheds were then extrapolated to the entire watershed using local load per unit area. Since septic systems contribute to loads estimated for monitoring stations, the extrapolation should reflect shoreline septic systems. However, if shoreline septic system in the areas immediately adjacent to South Puget Sound are more numerous or if effluents are less attenuated, then the extrapolation could underestimate septic contributions. To account for this, a separate estimate of nutrient loading was developed for on-site septic systems located within the study area but outside of municipal wastewater services areas and monitored watersheds.

We also calculated the natural nutrient conditions, which includes the concentrations and loads of nutrients in rivers and streams that drain into South and Central Puget Sound in the absence of human sources of nitrogen. A meta-analysis using various methods was carried out using historical and current ambient monitoring data, rainfall data, and data from other studies. The median value from these various methods was then used to calculate the natural condition.

Methods

In order to gain a comprehensive understanding of nutrient loading into South and Central Puget Sound, we need estimates of nutrient loads from multiple sources. These estimates are also necessary for input data into the GEMSS model. The major terrestrial sources of nutrients discussed in this report are:

1. *Watershed Loads:* from rivers and streams whose watersheds drain the study area. Contributing sources include atmospheric deposition, natural watershed sources, septic systems, fertilizer applications, upstream wastewater treatment plants, stormwater, and other point and nonpoint sources. This study did not distinguish relative contributions of these different sources within the watersheds. If the modeling effort determines that rivers and streams contribute to low DO, then additional efforts will be needed to understand which of the sources must be controlled.
2. *Septic System Loads:* from near-shore on-site septic systems (outside of monitored watersheds) that enter groundwater and eventually the marine waters within the study area
3. *Wastewater Treatment Plant Loads:* from WWTP and industrial effluent discharging directly into marine waters. The term "WWTP" is used to represent both WWTP and industrial effluent.

Watershed Loads

Field Data Collection

Monthly monitoring was conducted at 38[1] rivers and streams throughout the study area between July 2006 and October 2007. This included physical in-situ instantaneous measurements of temperature, conductivity, pH as well as well as grab samples for laboratory analysis for several water quality parameters (Table 2). Included in Table 2 are a few additional parameters that were calculated from these measured parameters. These parameters are needed by the model to adequately characterize the water quality of inflows into South and Central Puget Sound.

Four of the 38 monitoring locations were on major rivers that flow into South and Central Puget Sound (Deschutes, Nisqually, Puyallup, and Green) where Ecology conducts monthly ambient monitoring. Since these sites were already monitored monthly for various constituents, only supplemental monitoring was conducted.

[1] Originally, there were 39 sampling locations, including Sequalitchew Cr., which was found to be diverted upstream of the mouth and no outlet could be located. Also, intense winter storm events and widespread flooding precluded sampling at all sites during the November 2006 sampling run.

Table 2. Nutrient parameters included in the field monitoring effort.

Parameter Name	Parameter Abbreviation	Calculation Method
Measured Parameters		
Nitrate + Nitrite	NO23N	--
Ammonium	NH4N	--
Total Persulfate Nitrogen	TPN	--
Dissolved Total Persulfate Nitrogen	DTPN[1]	--
Ortho-Phosphate	OP	--
Total Phosphorus	TP	--
Dissolved Total Phosphorus	DTP	--
Total Organic Carbon	TOC	--
Dissolved Organic Carbon	DOC	--
Calculated Parameters		
Dissolved Inorganic Nitrogen	DIN	NO23N + NH4N
Particulate Organic Nitrogen	PON	TPN – DTPN[2]
Dissolved Organic Nitrogen	DON	DTPN – (NO23N + NH4N)[3]
Particulate Organic Phosphorus	POP	TP – DTP[2]
Dissolved Organic Phosphorus	DOP	DTP – OP[2]

[1]DTPN data collected at ambient stations were rejected due to a filter contamination issue
[2]For the stations where there were no DTPN data: PON = DON = 0.5*[TPN – (NO23N + NH4N)]
[3]For the stations where there were no DTP data: POP = DOP = 0.5*(TP – OP)

Eighteen of the 38 locations were monitored for each of the 15 months between August 2006 and October 2007, while 20 smaller tributaries were monitored monthly for the last four months (Figure 3). All samples were collected using standard operating protocols and processed at Ecology’s Manchester Environmental Laboratory using standard procedures. All lab replicates met the target mean relative standard deviation (RSD) for the entire dataset (Roberts, et al., 2008). Further details of the experimental design can be found in the QA Project Plan (Albertson, et al., 2007).

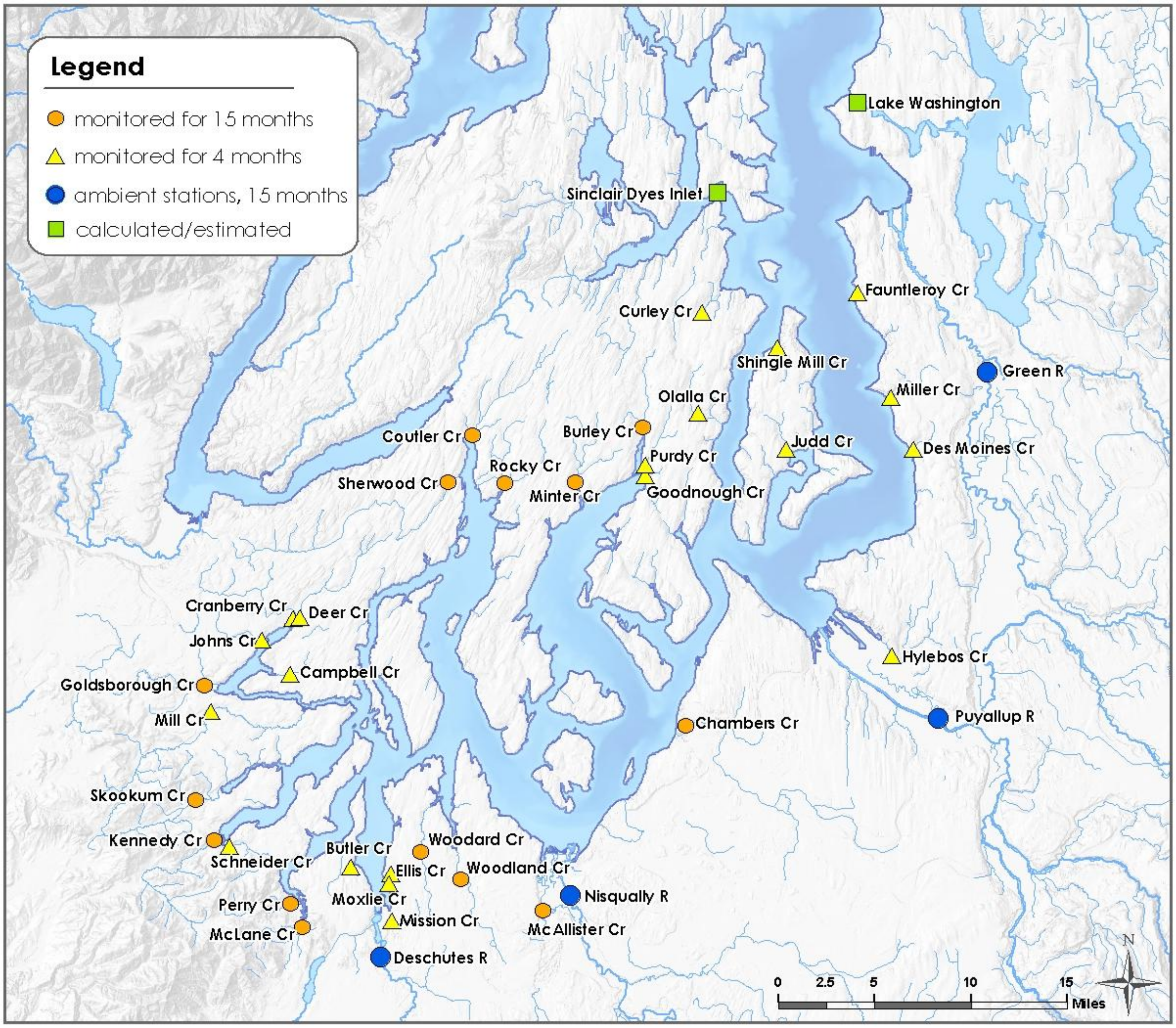

Figure 3. Locations of freshwater inflows monitored within the study area.

Even though no actual monitoring took place at Sinclair Dyes Inlet and Lake Washington/Ship Canal during the field effort, flow and concentration data for these two locations were estimated using data and information from the watersheds that they drain or from adjacent watersheds – these methods are described in more detail in the Interim data Report (Roberts, et al., 2008). Fifteen months of concentration data were estimated at both Sinclair Dyes Inlet and Lake Wahsington for all the parameters in Table 2 except for DTPN and DTP.

Estimating Daily Streamflow

In addition to water quality grab samples, field staff measured instantaneous streamflow at tributary streams during most sampling events. The United States Geological Survey (USGS) also maintains permanent continuous stream gages on several streams and on all four of the large rivers (Deschutes, Nisqually, Green, and Puyallup).

For rivers and streams that had a USGS gaging station located within their watershed, data from the USGS was retrieved and extrapolated to the mouth of the watershed by scaling the streamflow record by the larger watershed area and average annual rainfall.

Continuous streamflow was also estimated for watersheds which did not have a USGS gaging station located within their watershed, but where Ecology collected discrete streamflow measurements. This was done as follows:

1. Identifying nearby continuously gaged stations in watersheds of similar size, land use and proximity
2. Normalizing this continuous streamflow record by drainage area and average annual rainfall
3. Scaling the normalized streamflow by the area and average annual rainfall of the target watershed.

The same approach was used for watersheds with no flow measurements, such as direct inflows. In the end, we had a suite of predicted continuous daily streamflows at the *mouth* of each gaged and ungaged watershed within the study area. Estimated flows were compared to discrete measurements where available. Plots of predicted and observed flows at all stations which did not have a USGS gage station and where instantaneous flow measurements were made are presented in Appendix B.

Observed and predicted flows were comparable across all sites; however, predicted flows were noticeably lower than observed flows at the following four creeks: Moxlie, Ollala, Purdy and Shingle Mill. These creeks may have a stronger groundwater influence which is not captured by our predictions. The small size of these inflows means that they will not have much of an individual impact on the circulation or water quality of Puget Sound.

Flow formulations for a few rivers/watersheds used a slightly more complex equation using data from more than one USGS gage – note that some of these have been revised from the original formulations presented in the interim data report using updated watershed areas and flow scale factors. Flows for the Nisqually River were also updated to account for a water diversion by the Centralia Power Company. The updated flow equations are presented in Table 3.

Table 3. Source information for estimating streamflow from watersheds that used multiple USGS flow gages.

Watershed	USGS Source Gages	Equation to Estimate Flow
Lake Washington	Cedar River Mercer Creek Juanita Creek Issaquah Creek Sammamish River	$Q_{Lk\ Wash} = 1.7080 * (Q_{Cedar} + Q_{Mercer} + Q_{Juanita} + Q_{Sammamish})$
Sinclair/Dyes	Huge Creek	$Q_{Sinclair} = 26.98 * (Q_{Huge})$
Green River	Green River – Auburn Sammamish River	$Q_{Green} = 1.1028 * (Q_{Auburn}) + 0.3701* (Q_{Sammamish})$
Nisqually River	Nisqually River – McKenna Centralia Power Canal	$Q_{Nisqually} = 1.2230 * (Q_{McKenna} + Q_{Centralia\ Power})$

Watershed Delineations

River and stream monitoring did no always occur at the mouth of each watershed. To capture the nutrient loading from all the watersheds areas draining into South and Central Puget Sound, we had had to extrapolate nutrient loads from the monitoring station (where data were collected) to the mouth of each watershed, as well as to all unmonitored locations – this extrapolation is described in the next few sections).

Figure 4 shows the delineations for monitored watersheds, unmonitored watersheds, and the final set of watersheds for which we developed nutrient loading estimates (right most figure).

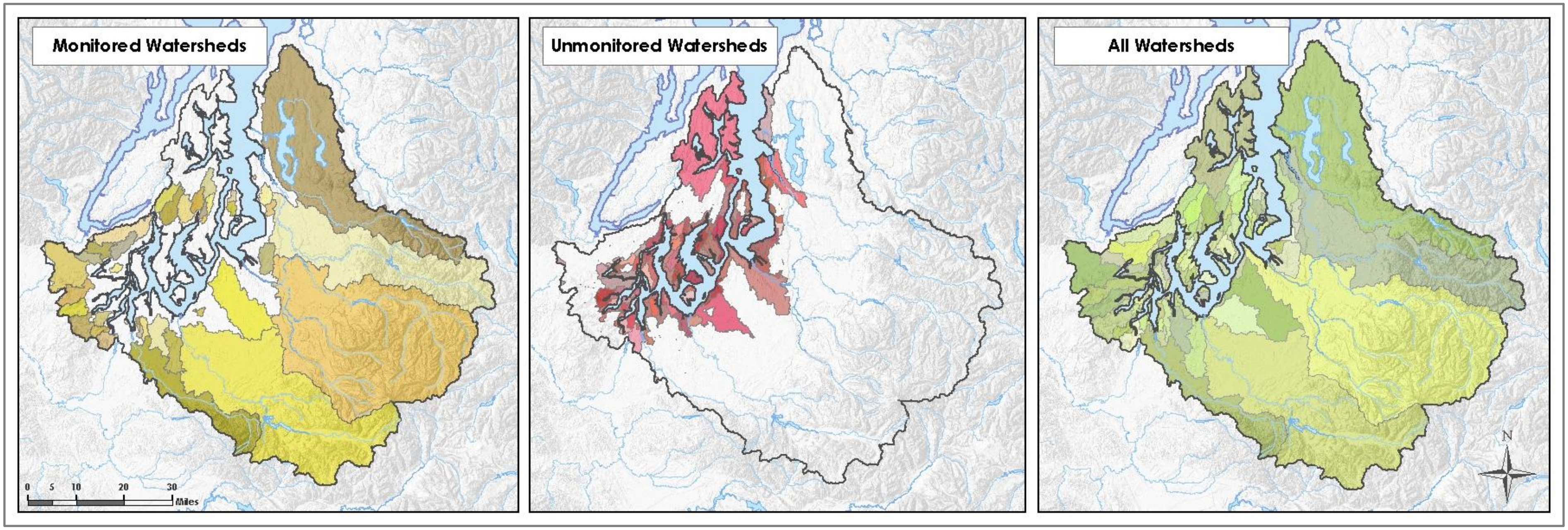

Figure 4. Delineations of monitored watersheds (left), unmonitored watersheds (center) and the final set of all the watersheds in the study area for which nutrient loading estimates were developed.

There are a total of 75 watersheds in the study area (Figure 4, right). These watersheds were delineated during Phase 1 of the South Sound Water Quality Study (Albertson, et al., 2002). These delineations were based on a 30 m digital elevation model (DEM) and performed using available tools in ArcGIS which use the information derived from the DEM to assess how water flows across the landscape and then determine watershed boundaries.

Each of the final set of watersheds in Figure 4 is further identified in Figure 5, with labels for the watershed name and the location at which each watershed flows into South or Central Puget Sound. The watersheds that were monitored for 15 months were used in the statistical analysis, (described in the next section) to develop daily nutrient loading estimates for all 75 watersheds in the study area.

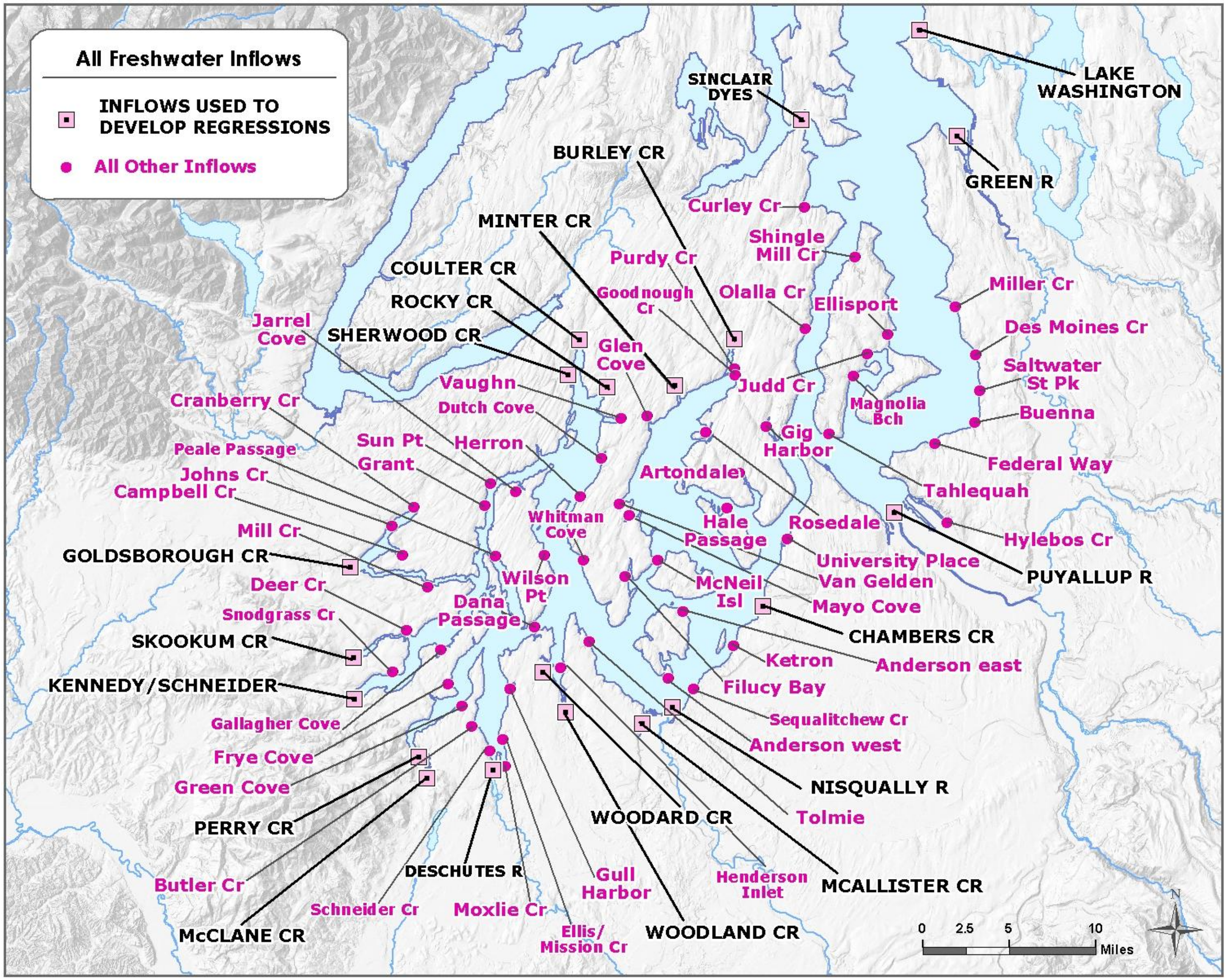

Figure 5. All freshwater inflows into the GEMSS model of South and Central Puget Sound for which daily concentrations were developed for the 2006-2007 calendar years

Predicting Daily Concentrations

Data from the field monitoring effort were used to estimate daily nutrient concentrations for all 75 watersheds/tributaries that drain South and Central Puget Sound, as identified in Figure 5. A statistical method called multiple linear regression was used to predict daily nutrient concentrations for the rivers and streams draining these watersheds. This statistical approach relates concentrations to flow patterns, time of year, and season using a best-fit to monitoring data. The multiple linear regression equation used in this analysis is given by:

Equation 1

$$\log(C) = b_0 + b_1 \log(Q/A) + b_2 [\log(Q/A)]^2 + b_3 \sin(2\pi f_y) + b_4 \cos(2\pi f_y) + b_5 \sin(4\pi f_y) + b_6 \cos(4\pi f_y)$$

where C is the observed parameter concentration (mg/L), Q is streamflow (cms), A is the area drained by the monitored location (km^2), f_y is the year fraction (dimensionless, varies from 0 to 1), and b_i are the best-fit regression coefficients. Logarithms of concentration and flow were used given the order of magnitude variability in the source data between different watersheds.

Of the 75 watersheds that are within the study domain, 20 watersheds had sufficient monitoring data available to calculate regression coefficients (i.e. the 14 watersheds where we collected 15 months of monitoring data, plus the four ambient stations as well as Lake Washington and Sinclair/Dyes Inlet). These watershed areas occupy 82% of the total study area.

For these 20 more intensely monitored locations, all six variables in Equation 1 are known values (from available concentration data, streamflow data, watershed area and time of year) except for the coefficients (b_i). The multiple linear regression model solves Equation 1 and determines the optimum combination of b_i coefficients that will yield the best fit between predicted and observed concentrations for each parameter of interest. The regression coefficients, b_i, were determined for each measured parameter[2] listed in Table 2 and for all 20 watersheds where sufficient monitoring data were collected.

Regressions were performed using the *Regression* tool within the *Analysis TookPak* add-in for Excel. In addition to the best-fit coefficients, the Excel output included an F value indicating the significance of the relationship, an R^2 and adjusted R^2, as well as a table of residuals. Model fit was evaluated based on the significance of the regression relationship (F value and p value), the adjusted R^2 value and the R^2 value generated by fitting a linear trend line to a plot of predicted vs. observed concentrations, and an evaluation of residual plots.

Outliers in the observed data were identified and removed from the dataset since the regression model would bias the relationship by trying to fit one extreme data point. The reported value was considered an outlier if it was more than three standard deviations away from the mean of the observed dataset for each specific parameter and stream. In many cases, however, the outlier was an unusually high concentration of a particular parameter that occurred only during the November 2006 sampling run which coincided with a storm event that caused widespread flooding. In this case, the observed value was not considered an outlier but representative of the

[2] Regressions were also developed for temperature, dissolved oxygen and pH, but are not included in this report.

natural response of the river or stream to the high flow event. Outliers associated with high flow events were therefore retained in the regression analysis.

If the regression relationship was not significant ($P > 0.05$), the least significant variable (the one with the largest p value) was removed from the equation and the regression was run for a second time to generate a new set of regression coefficients. This was done iteratively by removing up to two variables for each parameter. If the regression was still not significant after removing two of the least significant variables, the original coefficients determined by including all six original variables were used.

In the end, we had a set of watershed-specific multiple regression model coefficients (b_i) for each parameter at each of the 20 watersheds where we had 15 months of data. The watershed-specific regression coefficients were first used to predict daily concentrations using daily streamflows at the mouth of these watersheds for the calendar years 2006-2007.

Daily concentrations were compared to observed concentrations to see how well the model performed. Since monitoring did not always occur during the largest flow event, the regression model tends to extrapolate patterns to higher flows, potentially producing a source of error. To minimize the error due to this extrapolation, the maximum concentrations recorded in the monitoring data were used to cap predicted concentrations for all parameters. In addition, predicted concentrations below the detection limit were replaced with a value equal to the detection limit for the specific parameter. A smearing adjustment was then applied to correct for bias due to retransformation from log space (Cohn, et al., 1992).

Model coefficients developed for these 20 'original' watersheds were then applied to 'target' watersheds where we either had only four months of data as well as to watersheds where we had no data (i.e. to the 18% of the study area that did not have sufficient data to develop regression coefficients). Regression coefficients developed for 'original' watersheds were applied to 'target' watersheds that were in close proximity. For example, the regression coefficients determined for the McLane Cr. watershed using the 15 months of data collected from McLane Cr., were also applied to Butler Cr. and Schneider Cr. Equation 1 was then used to predict daily concentrations of parameters for these target watersheds using the target watershed's streamflow and area for the Q and the A in Equation 1.

Figure 6 illustrates which set of watersheds regression coefficients were applied to which target watersheds. The watersheds where we collected four months of data served as spot checks to see how well predicted concentrations matched observed data. The result was continuous daily streamflow and concentration data for all parameters of interest and for all watersheds draining into South and Central Puget Sound.

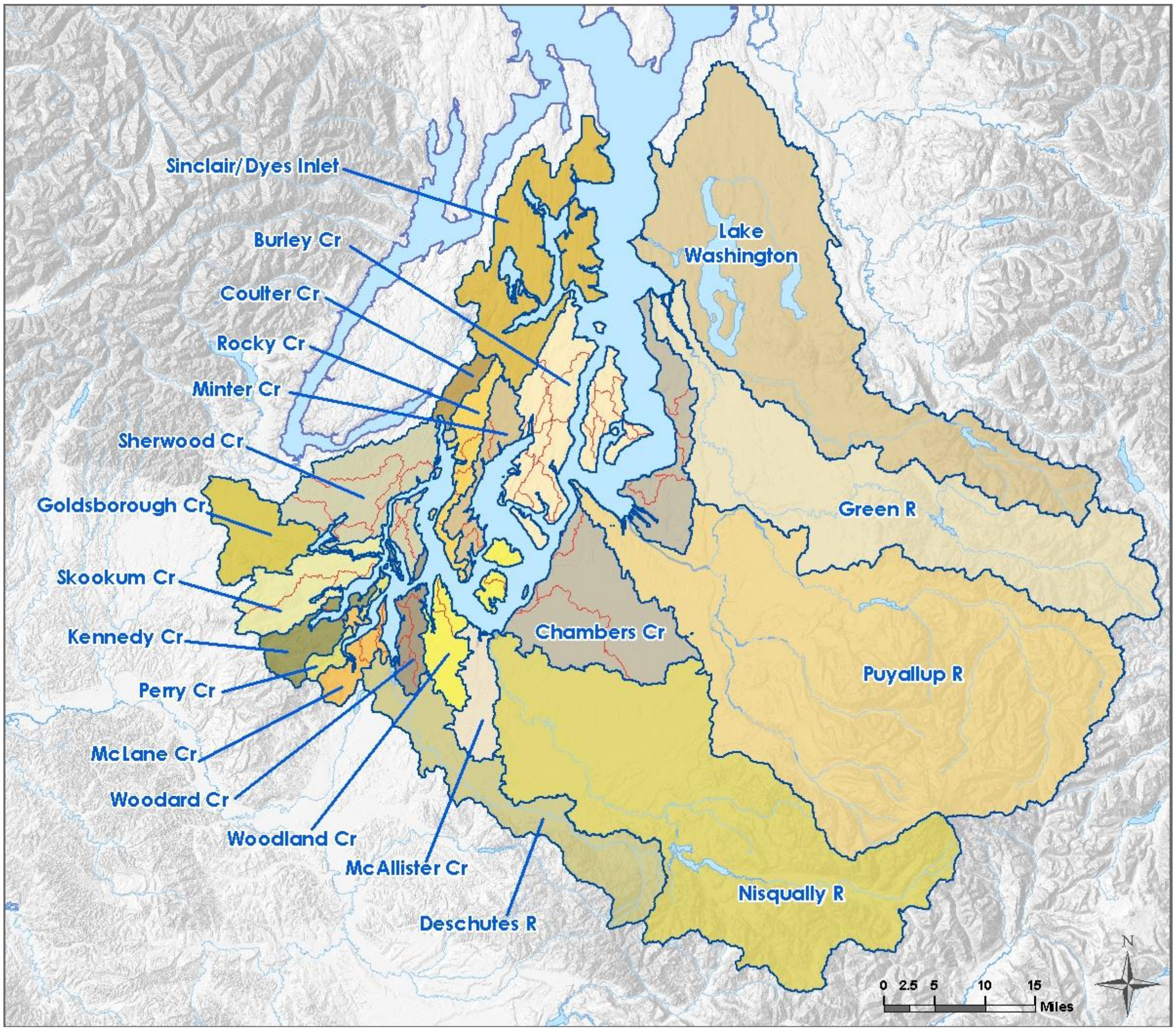

Figure 6. Map showing groupings of target watersheds labeled according to the 20 rivers and streams for which regressions were developed and then applied to these target watersheds.

Calculating Daily Loads

Continuous daily loads from rivers and streams were calculated from the predicted daily concentrations and daily flows for the years 2006 and 2007 as follows:

Daily load = (predicted daily concentration) x *(daily streamflow)*

Predicted loads were then compared with observed loads (for those locations where we had data).

Septic System Contributions

On-site septic systems are another source of nutrient loads into the marine waters within the study area. On-site septic system nutrient loads *upstream* of the monitoring location are included in our estimates of watershed loads. The extrapolation to the mouth of each watershed (and to unmonitored watersheds) should therefore reflect shoreline septic systems. However, if on-site septic systems in the unmonitored regions adjacent to South Puget Sound are more numerous or if effluents are less attenuated, then this extrapolation could underestimate DIN loads contributions from septic systems.

We therefore need an estimate of DIN loads from on-site septic systems from regions outside of monitored watersheds and outside of municipal wastewater service areas – from here on, this region is referred to as the 'exclusive area.' The estimate was developed by an analysis by Whiley (2010) using a Geographic Information System (GIS) based approach which used the following information: residences using on-site wastewater systems, wastewater flow rates, DIN concentrations in the wastewater, and DIN attenuation levels (percent loss of DIN as it moves from the septic system to the marine water) in the environment.

Since many of the parameters (e.g. DIN attenuation) used in the analysis can have significant variability, a Monte-Carlo analysis approach was applied to generate a range of potential DIN loading estimates from the exclusive area. DIN loading from on-site septic systems within the exclusive area were estimated for both upland (> 150 m from the shoreline) and shoreline (< 150 m from the shoreline) regions, since attenuation levels vary as a function of distance from the shoreline. The method is described in more detail and is included in Appendix C.

We used the results from Whiley's (2010) analysis to see if our extrapolated watershed loads adequately capture on-site septic system loads from the shoreline fringe. This was done by first calculating the difference between the mean annual DIN load per unit area from *all* watersheds (i.e. extrapolated loads) and the mean annual DIN load from just the monitored watersheds. This difference was then compared to the load per unit area from on-site septic systems. If septic system loads are much *smaller* than the difference in loads from extrapolated and monitored regions, we can say that our extrapolated loads adequately capture nutrient loads from on-site septic systems in the exclusive area. If septic system loads are *larger* than the difference in loads from extrapolated and monitored regions, we can say that our extrapolated loads do not adequately capture nutrient loads from on-site septic systems in the exclusive area, and these loads will have to be added as a subsidy. This comparison was done and is discussed in the results section.

Wastewater Treatment Plant Loads

Field Data Collection

There are 31 domestic WWTPs[3] and two industrial facilities[4] that discharge directly to South and Central Puget Sound. Each of these facilities operates under an individual National Pollutant Discharge Elimination System (NPDES) permit. This permit requires facilities to test their effluent on a routine bases (daily to weekly depending on the parameter) and report concentrations of these parameters to Ecology. Biochemical oxygen demand (BOD) and total suspended solids are required parameters, but most permits do not require monitoring for nutrients, including nitrogen, phosphorus or carbon.

During the 2006-2007 field monitoring effort, supplemental monitoring was conducted at 29 of these WWTPs. Seventeen of these 29 WWTPs were monitored for each of the 15 months between August 2006 and October 2007 and 12 smaller WWTPs were monitored monthly for the last three months (this included sampling at Simpson Kraft in Tacoma, one of two industrial effluents in the study area). Three WWTPs and one industrial effluent (US Oil & Refining) within the study area were not monitored (Figure 7), but effluent concentrations for these were estimated as described later. From this point onwards, reference to 'WWTPs' includes the two industrial discharges (Simpson Kraft and US Oil & Refining) in the study area.

Samples were 24-hour composites collected by each plant's sampling equipment (as required by their permit) and reserved for Ecology staff to collect each month[5]. The location of the sample varied from plant to plant, but was within the plant and as close to the outfall as possible. For smaller plants without 24-hour composite sampling equipment, Ecology staff collected grab samples. Samples were analyzed for each measured parameter listed in Table 2 (same as for freshwater monitoring stations), plus one additional parameter: Carbonaceous biochemical oxygen demand (CBOD)[6]. All samples were collected using standard operating protocols and processed at Ecology's Manchester Environmental Laboratory using standard procedures. All lab replicates met the target mean RSD for the entire dataset (Roberts, et al., 2008). Further details of the experiment design can be found in the QA Project Plan (Albertson, et al., 2007).

[3] This does not include the Messenger House Care Center, which we considered small enough to be negligible.
[4] There is a third industrial facility (Abitibi in Steilacoom), but their NPDES permit is currently inactive.
[5] Occasionally, WWTPs failed to reserve a sample for Ecology staff on a few instances, so fewer months of data are available.
[6] CBOD was not analyzed in rivers and streams where concentrations are nearly always below the reporting limit of 4 mg/L. Instead, CBOD is estimated from DOC.

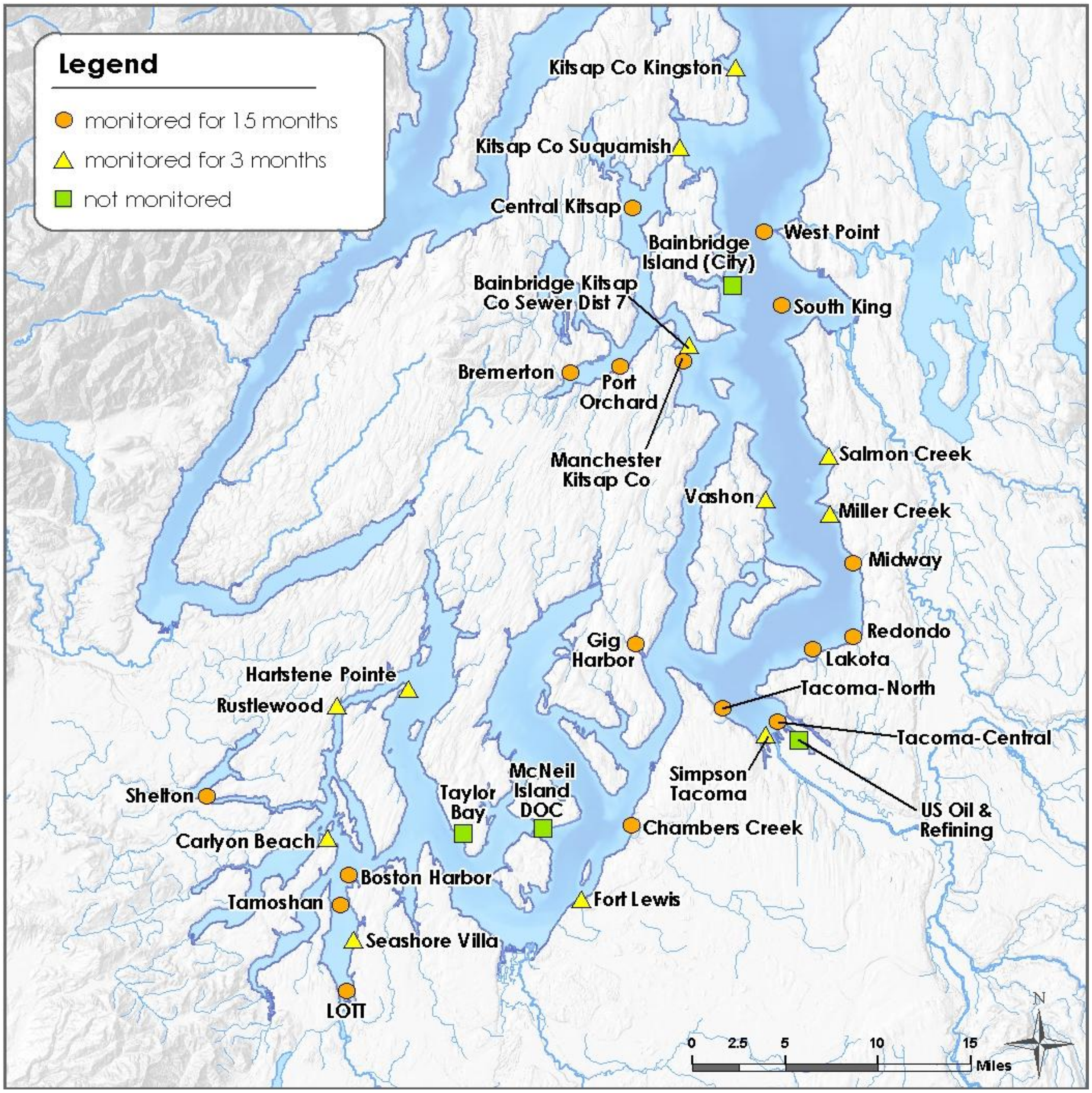

Figure 7. Locations of monitored and unmonitored WWTPs discharges within the study area.

WWTP Reported Data

In addition in-situ nutrient data from the 24-hour composite samples, we were able to get additional data from Discharge Monitoring Reports (DMRs) that WWTPs are required to submit as part of their NPDES permit. Much of this data is available online through the Ecology's Water Quality Permit Life Cycle System (WPLCS), and in most cases, includes data on effluent flow and CBOD. Data reported in DMRs was often used for WWTPs where we had fewer or no data. Because most plants are not required to monitor nutrients, little supplemental data were available.

Daily Effluent Flow

Plants report daily flows on paper copies of the DMRs, which are submitted to Ecology or EPA. However, only monthly average flows are captured electronically by Ecology or EPA.

All large (> 10 mgd) and most of the medium (4-10 mgd) WWTPs participated in this study by providing electronic daily effluent flow data to Ecology for the time period of the field monitoring effort (July 2006 – October 2007). For the rest of the medium WWTPs and a few small ones (< 4 mgd), daily effluent flow data reported in hard copy DMRs was physically entered by Ecology staff for this same time period. For all other small WWTPs, monthly average flows were retrieved electronically and used to represent daily flows.

Predicting Daily Concentrations

Daily concentrations of nutrients were predicted for all 33 WWTPs within the study area using a similar approach to that used to estimate watershed concentrations. Monthly data from the field monitoring effort were used to estimate daily nutrient concentrations for these 33 WWTPs using a statistical method called multiple linear regression. This statistical approach relates concentrations to flow patterns, time of year, and season using a best-fit to monitoring data. The multiple linear regression equation used for WWTPs is given by:

Equation 2

$$\log(C) = b_0 + b_1 Q + b_2 Q^2 + b_3 \sin(2\pi f_y) + b_4 \cos(2\pi f_y) + b_5 \sin(4\pi f_y) + b_6 \cos(4\pi f_y)$$

where C is the observed parameter concentration (mg/L), Q is effluent flow (cms), f_y is the year fraction (dimensionless, varies from 0 to 1), and b_i are the best-fit regression coefficients. Note that unlike Equation 1 that was used for watersheds, Equation 2 does not have the flows normalized by the area (since drainage area is irrelevant to WWTPs), and the effluent flow is not transformed into log space since there is much less flow variability in WWTPs than in rivers.

Plant and parameter specific regression coefficients were determined for all 17 WWTPs that were monitored for 15 months. These WWTPs account for 89% of the total mean annual discharge of all WWTPs within the study area. For these 17 more intensely monitored WWTPs, all six variables in Equation 1 are known values (from available concentration data, effluent flow data, and time of year) except for the coefficients (b_i). The multiple linear regression model solves Equation 2 to determine the optimum combination of b_i coefficients that will yield the best fit between predicted and observed concentrations for each parameter of interest. The regression coefficients, b_i, were determined for each measured parameter listed in Table 2 (as well as for CBOD) using the same Excel tool as we did for estimating watershed concentrations.

In the end, we had a set of WWTP-specific multiple regression model coefficients (b_i) for each parameter at each of the 17 WWTPs where we had 15 months of data. The WWTP-specific regression coefficients were first used to predict daily concentrations using daily effluent data at these WWTPs for the calendar years 2006-2007. In addition, concentrations of additional parameters were calculated from these predicted concentrations, as listed in the bottom half of Table 2.

Daily concentrations were compared to observed concentrations to see how well the model performed. Since monitoring did not always occur during the largest or smallest effluent flow, the regression model tends to extrapolate patterns to higher and lower flows, potentially producing a source of error. To minimize the error due to this extrapolation, predicted concentrations were capped by the maximum and minimum observed concentrations in the monitoring data for each specific plant.

As mentioned earlier, 12 WWTPs had limited data, while three others had no data – these contribute to 11% of the mean annual flow of all WWTPs that discharge within the study area. Since the available data for these 15 WWTPs were insufficient to develop plant-specific regression coefficients, a different approach was used to estimate daily nutrient concentrations:

1. All WWTPs for which regressions were developed were first divided into three size groups according the magnitude of their effluent flow: large (> 10 mgd), medium (4-10 mgd) and small (< 4 mgd).
2. Daily concentration templates were developed for each size group – these concentrations were the average of each nutrient parameter averaged across all plants that fell within each size group (i.e. for the 'medium' template, the NO23N concentration was the average NO23N concentrations of all medium plants). We therefore had concentration templates representative of all large, medium, and small WWTPs in the study area for which regressions were developed.
3. These templates were applied to all other WWTPs (those that were monitored for three months or not monitored at all) according to which size group they fell in. For example, Fort Lewis, Miller Creek, and Salmon Creek WWTPs are all medium plants that were only monitored for three months – the medium concentration template was therefore applied to all three plants to represent their daily nutrient concentrations.

The WWTPs where we collected three months of data served as spot checks to check how well the templates concentrations matched observed data.

The above methodology was applied to all WWTPs except the Carlyon Beach WWTP and the two industrial discharges. Nitrogen concentrations at Carlyon Beach (53 mg/L median for TPN and NO23N) are much higher than the typical small WWTP in the study area (9.81 mg/L annual average TPN for small plants). The concentration templates were therefore an inaccurate representation of the effluent water quality for this particular plant. Since we collected three months of data at this plant, we calculated the average of these three months of data for all parameters and applied these averages for the full 2006-2007 time period.

Three months of data were also collected at Simpson Kraft (Tacoma), which had effluent nitrogen concentrations that were much lower than municipal wastewater effluent. We used this data to develop a simple linear regression relationship (not *multiple* linear regression) between flow and effluent concentration for all parameters except CBOD; a simple rather than a multiple linear regression was used because of insufficient data. These linear equations were then used to predict daily concentrations for these parameters using daily flows. Since sufficient CBOD data were available from the DMRs for Simpson Kraft, we were able to develop a specific multiple linear regression for CBOD.

We did not collect any data at US Oil & Refining, and since this is not a WWTP, the concentration templates developed using WWTP data and regressions could not be applied to their effluent. However, NH4N and CBOD data were available through WPLCS, and site-specific multiple linear regression relationships were developed for these two parameters. For the rest of the parameters, we worked with the industrial permit manager who had typical values for a few parameters. In addition, we made the following assumptions for US Oil & Refining:

- All nitrogen in their effluent was in the form of NH4N.
- OP concentrations were assumed to be a constant 0.4 mg/L (about 10 times lower than that typical of municipal wastewater effluent). This is based on an estimate by Environmental Protection Agency (EPA) for petroleum refineries (EPA 1996).
- All organic carbon was in dissolved form (i.e. TOC = DOC).

Once we had daily flow and concentration data for each WWTP in the study area, we sent a letter to each WWTP describing the specific method we had used to develop the data for their plant. The letters also included a description of the South Puget Sound Dissolved Oxygen Study and included a spreadsheet attachment of the daily effluent flow and daily nutrient concentration data we had established for each plant (either using regressions or using the templates). WWTPs reviewed the data for their plant and either confirmed that these data were reasonable, or responded with better or new data.

A few WWTPs for which we had used monthly average flow instead of daily flows responded by providing us with daily flows; we therefore replaced our monthly values with their daily values. If plants responded with new or more extensive data for any particular parameter (e.g. South King and Fort Lewis), we used that data to developed plant-specific regressions for that parameter and replaced the original daily concentration estimates we had for that plant with the concentrations predicted by the new regression results.

Calculating Daily Loads

Continuous daily loads from WWTPs were calculated from the predicted daily concentrations and daily flows for the years 2006 and 2007 the same way as for watershed loads:

Daily load = (predicted daily concentration) x *(daily effluent flow)*

Even though we capped WWTP concentrations by the maximum of observed instantaneous concentrations, many WWTPs had a few unusually high spikes in their loads due to a combination of regression parameters and coincident high plant flows. Though these spikes do not strongly influence seasonal inputs, we also capped all loads by the maximum instantaneous loads measured in the data collection program. Predicted loads were then compared with observed loads (for those locations where we had data).

Natural Conditions

An important part of this study involves the development of natural conditions. Natural conditions in this study refer to the concentrations of nutrients in rivers and streams before significant human influences/sources of nutrients existed. By definition, there would be no WWTP or septic system inputs into Puget Sound under natural conditions. There are various natural sources and sinks of nitrogen in streams, including: rainfall, riparian and terrestrial vegetation, spawning salmon, various in-stream nitrogen biogeochemical cycling processes, and decomposition of organisms.

Once natural concentrations are established, they can be used as inputs into the water quality model so that we can evaluate the water quality of Puget Sound under natural conditions.

Since monitoring of rivers and streams has occurred post-human development, we do not have historic water quality data that goes back far enough in time to reflect pristine, natural or pre-development conditions in rivers and streams draining to South and Central Puget Sound. Therefore, recent data has to be used to determine natural concentrations of nutrients in rivers and streams based on the least developed and most forested watersheds or older data reflecting lower populations and possibly less intense land use.

Ambient monitoring concentration data indicate seasonal variability. Many of the less developed watersheds have very low concentrations in the summer months. At these times, nitrogen becomes the limiting nutrient for primary productivity and in-stream processes likely decrease nitrogen export (Kantor et al., 1998). However, in other watersheds where groundwater nitrogen levels are high, such as the Deschutes River, decreasing storm flows reduces dilution in the summer months, resulting in higher concentrations. A single annual median concentration value is recommended because no single seasonal pattern holds across all watersheds and the concentration variability is far lower than the variability in flows due to storms.

We performed a meta-analysis to establish natural conditions for rivers and streams that drain into South and Central Puget Sound for the following parameters: TPN, NO23N, NH4N, TP and OP. This meta-analysis involved the use of several methods – the results of these different methods were then analyzed to establish natural nutrient concentrations. Each of these methods is described below.

Recent ambient water quality data at the mouths of rivers

Ecology maintains several ambient freshwater monitoring stations located throughout Washington. We used data collected between WY 2002-2009 from monitoring stations located closest to the mouths of watersheds that drain into South and Central Puget Sound as well as nearby less developed regions around Puget Sound. Table 4 lists the station locations selected.

The 10^{th} percentile of all the data for each parameter within each region listed above was calculated to represent a reasonable estimation of natural conditions. For TP, however, we only used data from WY 2007-2009 since there was a change in Manchester Environmental

Laboratory methods in 2003 and again in 2007 which did not allow us to pool older data with newer data.

Table 4. List of ambient monitoring stations grouped into different regions of Puget Sound that were used as part of the meta-analysis to establish natural conditions.

Puget Sound Region	Station Name(s)	Station ID	Percent Developed*
Within Model Domain			
Puget South	Deschutes River at E St. Bridge Nisqually River at Nisqually	13A060 11A070	23%
Commencement Bay	Puyallup River at Meridian St.	10A070	19%
Puget Main	Cedar River at Logan St./Renton	08C070	48%
Elliott Bay	Green River at Tukwila	09A080	33%
Near but Outside Model Domain			
Hood Canal	Skokomish River near Potlatch Duckabush River near Brinnon	16A070 16C090	5%
Strait of Juan de Fuca/Strait of Georgia (SJF/SOG)	Nooksack River at Brennan Samish River near Burlington Elwha River near Port Angeles	01A050 03B050 18B070	16%
Whidbey Basin	Skagit River near Mount Vernon Stillaguamish River near Silvana Snohomish River at Snohomish	03A060 05A070 07A090	8%

* Percent non-forested land cover based on the National Land Cover Dataset MRLC (Herrera, 2010).

Ambient water quality data from less-developed watersheds

Data from watersheds with less human development can serve as good indicators of natural conditions. We therefore chose Ecology's ambient stations located in the Nisqually and Skagit River watersheds, which are both less developed than other watersheds in Puget Sound. These two watersheds are also located in different regions of Puget Sound, providing broader geographic coverage. Ambient data from the following three stations were used:

1. Nisqually River at McKenna (11A080)
2. Skagit River near Mount Vernon (lower Skagit, 03A060)
3. Skagit River at Marblemount (upper Skagit, 04A100).

The median of all the data for each parameter for each station listed above was calculated for two time periods: (1) historic data from the 1960s and 1970s (depending on availability) and (2) recent data from WY 2009.

Atmospheric (rainfall) data

The National Atmospheric and Deposition Program's National Trends Network has stations that measure concentrations of nitrate and ammonia in rainfall throughout Washington State. Data from the following four stations located in western Washington were retrieved for WY 2002-2009:

1. Olympic National Park – Hoh Ranger Station (WA14)
2. North Cascades national Park – Marblemount Ranger Station (WA19)
3. Mount Rainer National Park – Tahoma Woods (WA99)
4. La Grande (WA21)

The median concentration of NO23N and NH4N was calculated for (1) the Olympic station only and (2) all four stations listed above. Of these four stations, the one located in the Olympics is upwind from Puget Sound watersheds and is therefore least influenced by local anthropogenic sources of nutrients, and was therefore chosen to represent another estimate of natural conditions.

Puget Sound Toxics Runoff Project

Ecology has an ongoing study, called the Puget Sound Toxics Loading Project, which estimated the concentrations of nutrients in surface runoff for both baseflow and stormwater events from watersheds with different land cover types (Herrera Environmental Consultants et al., 2009).

Field data for this project were collected and measured by Herrera Environmental Consultants. For this study, we used the median of the data collected from predominantly forested sub-basins within the Puyallup and Snohomish watersheds. These data were selected because under natural conditions, most of the watersheds that drain into Puget Sound were forested.

Hood Canal Dissolved Oxygen Program

The Hood Canal Dissolved Oxygen Program is a partnership of various organizations that conduct monitoring and analysis to address low dissolved oxygen levels in Hood Canal. As part of their analysis, they have estimated natural background NO23N concentrations for rivers and streams entering Hood Canal (Steinberg et al., 2010).

Results

Multiple Linear Regression

The multiple linear regression method used to estimate daily nutrient concentrations performed well in estimating the concentrations of most parameters when compared to observed data for both rivers and WWTPs. Overall, the method provides a better estimate of daily concentrations in rivers and WWTPs than using constant values or monthly averages, and was able to capture changes in concentration due to flow and seasonality.

For most parameters, predicted vs. observed *loads* compared better than predicted vs. observed *concentrations* across all streams and WWTPs. This was true even for those parameters that did not yield significant regression relationships or did not have high adjusted R^2 values. This is because the variability in flow exceeds the variability in concentration, resulting in predicted loads that match well to observed loads.

Table 5 presents a summary of the significance and adjusted R^2 values of the multiple linear regression relationships developed using concentration data in each of the 20 watersheds that had sufficient data. The majority of parameters (9 out of 13) had significant regression relationships for the majority of watersheds. For these watersheds, the regression equation explains 53-81% of the variability (median R^2 = 0.53-0.81) in measured concentrations.

Table 5. Overall significance and median adjusted R^2 values of regression relationships developed for each concentration parameter for each of the 20 watersheds that were used to develop regressions.

Parameter	% significant relationships	Median Adjusted R^2
DTPN	93%	0.75
NO23N	90%	0.81
OP	90%	0.78
DOC	90%	0.74
TP	85%	0.77
TPN	80%	0.68
DTP	78%	0.71
NH4N	68%	0.53
POP	61%	0.62
DON	43%	0.38
DOP	33%	0.17
POC	20%	0.01
PON	14%	0.17

Regressions for all forms of nitrogen (except NH4N) performed very well. Concentrations of NH4N are generally much lower than the other forms nitrogen, so even if NH4N predictions are less accurate, these concentrations will not significantly affect overall nitrogen loading estimates. The same applies to phosphorus and carbon; inorganic forms of phosphorus and carbon generally had stronger regression relationships than the organic forms of phosphorus and carbon, which typically have lower concentrations.

Table 6 presents a summary of the significance and adjusted R^2 values of the multiple linear regressions relationships developed using concentration data at each of the 17 WWTPs that had sufficient data. Regression relationships developed for WWTPs were not as strong as those that were developed for rivers. However, the regression method still provided a better fit to monitoring data than simple averages, as indicated by the root mean square errors calculated using multiple methods for Tacoma-Central plant. The Tacoma-Central plant was used for comparison because nitrogen levels in the effluent were more variable than at other plants.

Table 6. Overall significance and median adjusted R^2 values of regressions relationships developed for each concentration parameter for each of the 17 WWTPs that were used to develop regressions.

Parameter	% significant relationships	Median Adjusted R^2
DTP	47%	0.51
NO23N	41%	0.56
DTPN	35%	0.27
NH4N	35%	0.36
TPN	29%	0.20
TP	29%	0.41
OP	29%	0.32
TOC	24%	-0.03
CBOD	6%	0.10
DOC	0%	0.06

Plots of predicted and observed concentrations and loads for all four large rivers (Deschutes, Nisqually, Puyallup, and Green) and all large WWTPs (> 10 mgd) are presented in Appendix D and Appendix E. These appendices also include tables presenting the difference and the root means square error (RMSE) between predicted and observed concentrations for all rivers, streams, and WWTPs where water quality data were collected.

The rest of this report focuses primarily on DIN since (1) nitrogen is the nutrient of greatest concern in South Puget Sound and (2), of all the forms of nitrogen, DIN is the most relevant in the context of low DO levels. However, the same set of figures presenting the data we have for various other forms of nitrogen, phosphorus, and carbon are included in Appendix F and Appendix G.

Watershed Loads

Table 7 compares annual and September 2007 DIN loads calculated from the multiple linear regression method with those calculated from the monthly field monitoring data. The annual DIN load is the mean for the Water Year 2007 (WY07).

The purpose of this comparison is to illustrate that the regression method is a realistic and reasonable method of estimating loads since, in most cases, these estimates are similar to measured loads. It should be noted that the annual subtotals and totals for the monthly data do not include loads from streams that were monitored for 4 months. However, the loads from these streams make up only 4% of the annual South Sound subtotal. Overall, DIN loads derived from the regression are slightly higher, but comparable to loads calculated from the monthly data.

The annual monthly data values in Table 7 are different from those presented in Table 18 of the Interim Data Report (Roberts, et al., 2008). Table 18 in the data report requires clarifications and a correction. First, Table 18 included *all* streams monitored as part of the 2006-07 data collection program. However, 20 of these streams did not have year-round data. The annual loads were calculated from the available data, which are biased low due to dry-season flow characteristics. No equivalent year-round data are available with which to compare regression results, and these sums have not been included in the present loading report.

Second, the annual averages in Table 18 of the Interim Data Report also did not include November 2006 information because a large storm event precluded sampling during this month; this results in annual values biased low since loads tend to be higher in November, particularly during such large storm events. Third, the annual averages included averages of both August 2006 and 2007, September 2006 and 2007, and October 2006 and 2007. However, to provide a direct comparison for this report, the water year 2007 monthly values (October 2006 through September 2007) values were used. Finally, the annual averages for the larger river systems (Deschutes, Nisqually, Puyallup, Green, Lake Washington, and Sinclair Dyes Inlets) included a calculation error that resulted in loads biased low. This report corrects those values and presents the annual averages for WY07.

The estimates derived from the regression method are our best estimate of loading several reasons: these estimates are available at a daily time step accounting for changes with flow and season, they include loads from unmonitored regions, and there are no gaps throughout the 2006-2007 study period. A complete table of summer and annual DIN loads estimated from the regression method for all watersheds in South and Central Puget Sound is included in Appendix F.

Table 7. Comparison of DIN loads from rivers estimated from (1) the regression method and (2) from monthly data collected during the field monitoring period.

Stream/River Name	ANNUAL DIN Load (kg/d)[1]		SEPT. 2007 DIN Load (kg/d)[2]	
	Regression	Monthly Data	Regression	Monthly Data
South Puget Sound				
Burley Cr	42	60	24	24
Butler Cr	1.4	--	0.1	0.1
Campbell Cr	4.3	--	0.9	0.2
Chambers Cr	428	422	136	112
Coulter Cr	8.8	14	1.8	2.6
Cranberry Cr	18	--	3.8	2.1
Deschutes R	921	729	197	198
Ellis Cr	4.8	--	1.3	1.0
Goldsborough Cr	66	74	6.8	4.9
Goodnough Cr	5.1	--	1.5	2.4
Johns Cr	17	--	3.5	4.4
Kennedy Cr	68	98	9.0	3.5
McAllister Cr	168	240	36	51
McLane Cr	25	39	3.3	0.8
Mill Cr	68	--	7.1	1.0
Minter Cr	40	63	12	13
Mission Cr	2.6	--	0.7	0.8
Moxlie Cr	4.0	--	0.9	15
Nisqually R	1288	1011	190	199
Perry Cr	14	10.0	4.9	0.6
Purdy Cr	3.0	--	0.2	1.0
Rocky Cr	30	28	12	3.2
Sherwood Cr	3.4	3.2	0.7	0.4
Skookum Cr	50	76	5.2	0.4
Woodard Cr	26	18	7.2	6.5
Woodland Cr	148	148	48	57
South Sound Subtotal	**3454**	**3033**	**713**	**705**
Central Puget Sound				
Curley Cr	38	--	11	4.1
Des Moines Cr	21	--	5.6	2.2
Green R	1978	2279	429	427
Hylebos Cr	71	--	19	18
Judd Cr	13	--	3.7	3.7
Lake Washington	509	559	28	36
Miller Cr	33	--	8.9	6.4
Olalla Cr	2.7	--	0.2	5.1
Puyallup R	2353	1862	613	734
Shingle Mill Cr	3.1	--	0.2	4.1
Sinclair Dyes	384	457	85	107
Central Sound Subtotal	**5405**	**5157**	**1204**	**1347**
South and Central Puget Sound Total	**8859**	**8190**	**1917**	**2055**

[1]For the regressions, these values are the mean of the daily regressions for WY07 (October 2006 through September 2007); for the monthly data, the DIN loads these values are calculated from monthly grab samples collected in WY07, but without November 2006; no annual values are reported for streams with 4 months of data (denoted by '--').
[2]For the regressions, these values are the mean of September 2007 daily regressions; for the monthly data, these values are the instantaneous loads calculated from the September 2007 grab samples.

For all watersheds, the mean annual DIN load in 2007 was less than that in 2006. The mean annual DIN loads from all watersheds in the study area were 21% lower in 2007 than in 2006. Mean annual flows from all watersheds were also lower in 2007, by 19%, potentially accounting for a large proportion of this difference.

Figure 8 geographically illustrates median concentrations DIN for all watersheds in the study area for 2006 -2007. Note that only those watersheds that fall into the highest concentration category (i.e. largest dot size) are labeled. In addition, Figure 9 presents box and whisker plots of watershed DIN concentrations.

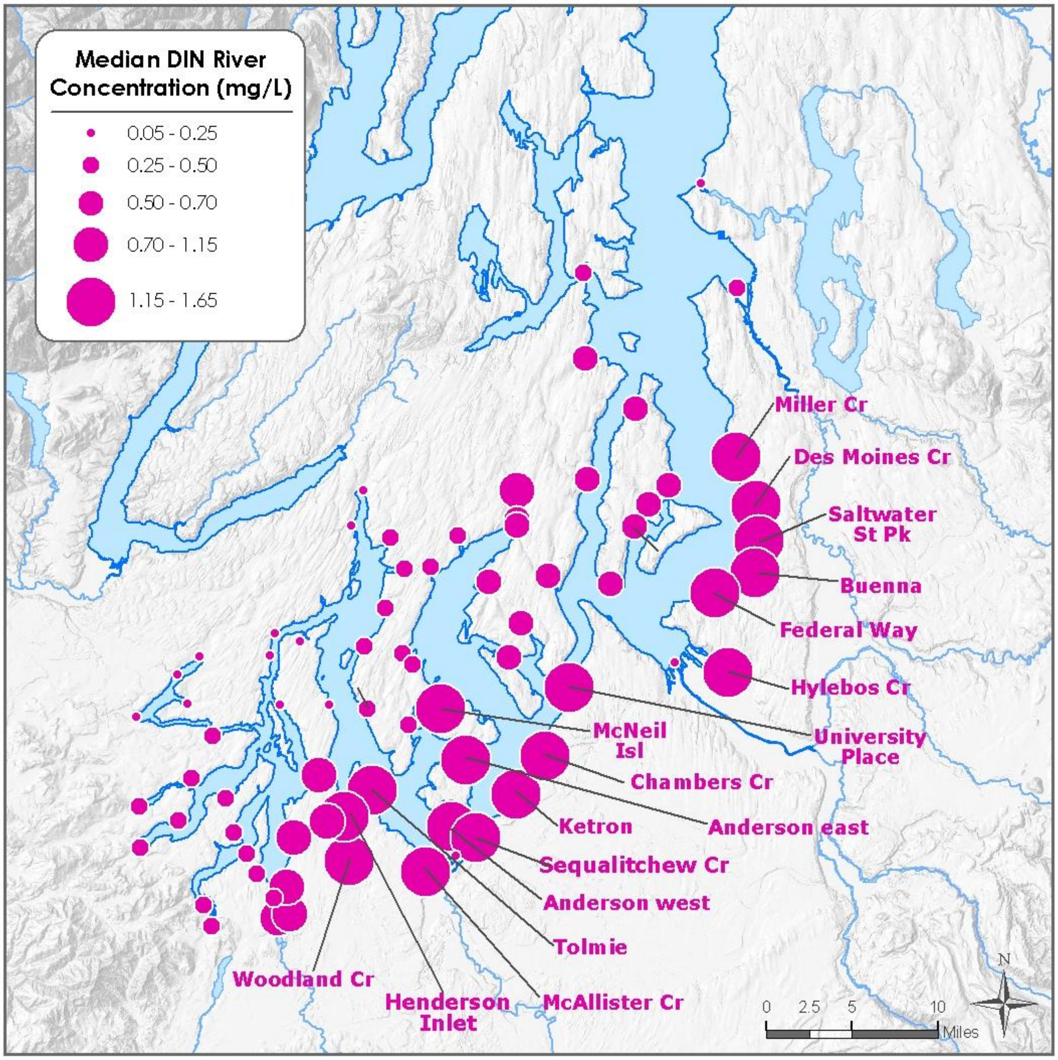

Figure 8. Median watershed DIN concentrations for 2006 through 2007.

The highest median concentrations of DIN (which is the form of nitrogen of greatest interest) are found in Woodland Creek, which was then extrapolated to the following watersheds: Anderson east and west, McNeil Island, Tolmie, Henderson Inlet. High median DIN concentrations were also found in McAllister Creek, for which concentration estimates were not extrapolated from another watershed, but were based on measurements taken at the monitoring station on McAllister Creek.

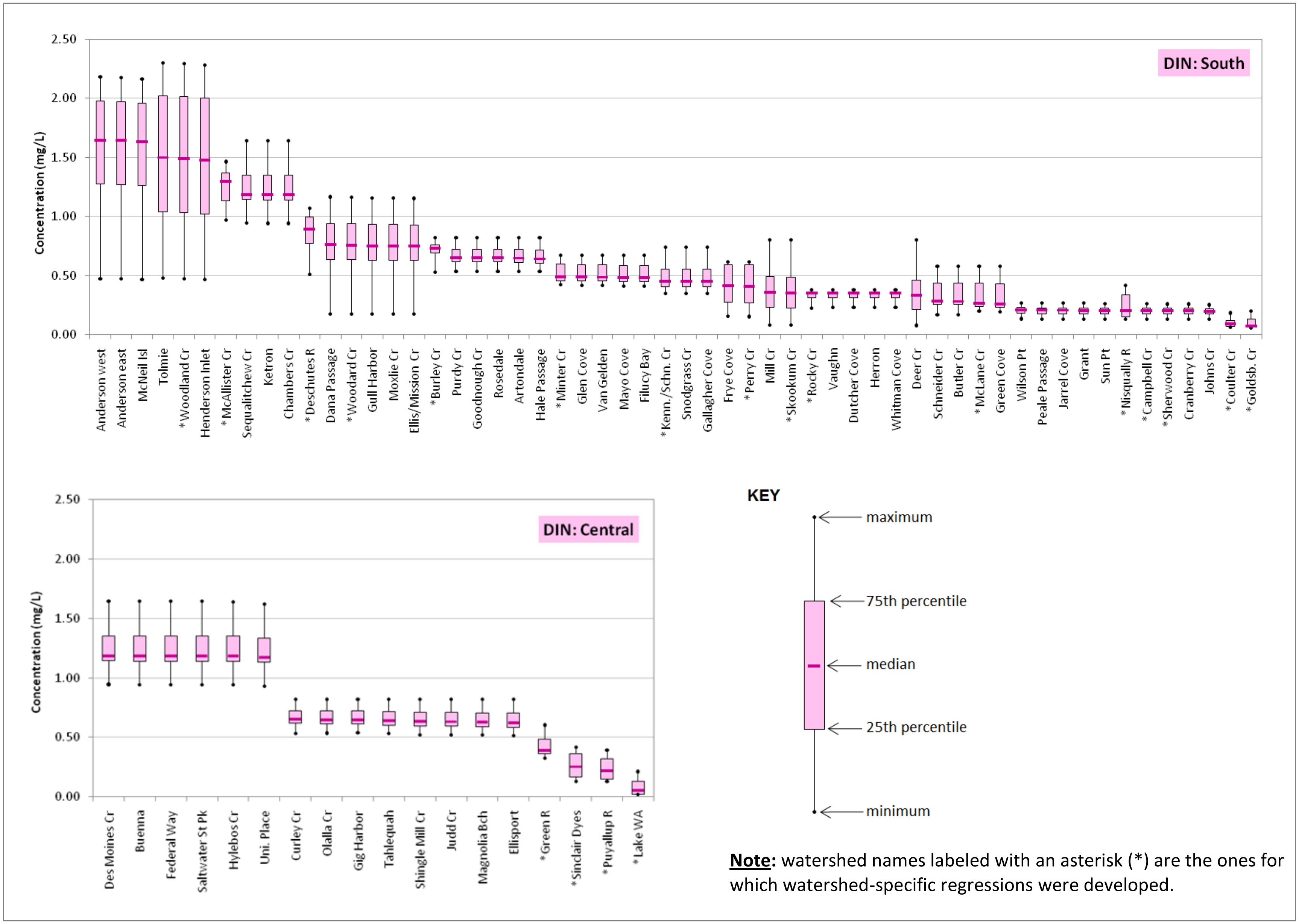

Figure 9. Box plots of DIN concentrations for 2006 – 2007 for watersheds in South (top) and Central (bottom) Puget Sound.

The box and whisker plots also show that most of these watersheds also have similar DIN concentration patterns – these watersheds are ones that are in close geographic proximity to each other, and where the same regressions relationships were applied (in this case, from Woodland Creek), resulting in similar predictions of DIN. The range of DIN concentrations found in rivers and streams in South Puget Sound are generally greater than the range of DIN concentrations found in rivers and streams in Central Puget Sound.

The watersheds that have high DIN concentrations are not necessarily the same ones that have high DIN loads since loads are generally higher for watersheds with higher flows and drainage areas. Figure 10 illustrates how all the larger rivers/watersheds in the study area have DIN loads that are an order of magnitude higher than the rest of the watersheds in the study area (note: only watersheds that have DIN loads greater than 100 kg/d are labeled). The three watersheds with the highest DIN loads are the Puyallup (2420 kg/d), Green (1942 kg/d), and Nisqually (1748 kg/d), and Deschutes Rivers (993 kg/d).

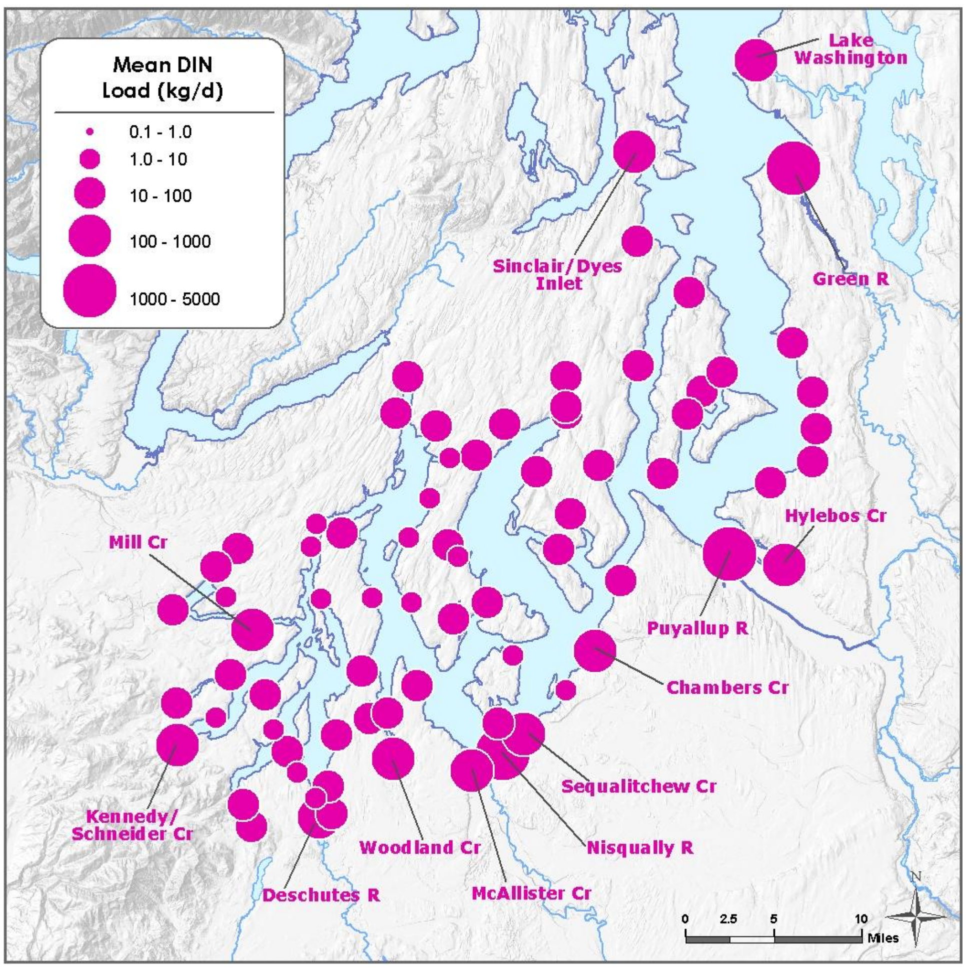

Figure 10. Mean DIN loads from watersheds during 2006-2007.

Though Figure 10 is useful for identifying the watersheds with the highest DIN loads, it does not account for difference in the size of each watershed (relative to other watersheds). We therefore normalized these loads by the size of each watershed to determine the ‘relative load’, as follows:

where *i* in the above equation represents a particular watershed in the study area. Relative loads greater than 1.0 are higher than average while relative loads below 1.0 are less than average (relative to the rest of the study area).

For example, the Puyallup River Watershed occupies 24.5% of the study area, but accounts for 20.7% of the total DIN load. Its relative load is therefore 20.7 divided by 24.5, which is equal to 0.85 (i.e. below average). Figure 11 illustrates the relative loads for all the watersheds in the study area, where darker colors represent higher relative loads.

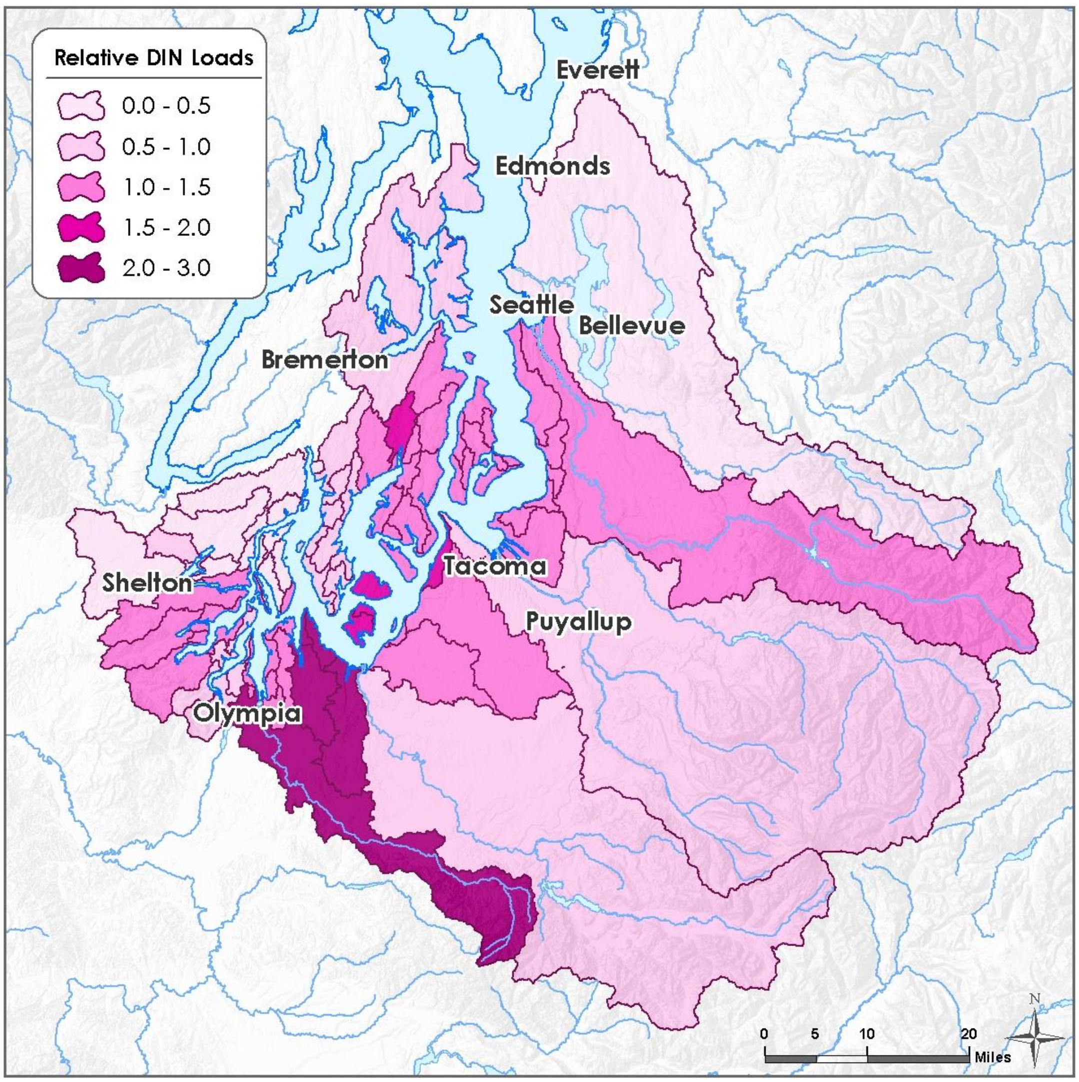

Figure 11. Annual relative DIN loads (ratio of fractional load to fractional area) from watersheds in the study area during 2006-2007.

Watersheds draining into Budd and Henderson Inlets in South Puget Sound, including the Deschutes River watershed, have the highest relative loads in the study area. These watersheds are generally more densely populated (higher population per area) than others within the study area, which might be the reason for higher relative DIN loads.

Since the Deschutes River drains into Capitol Lake before entering Budd Inlet, we also estimated daily flows, daily nutrient concentrations and daily loads at the outflow of Capital Lake. These concentrations and loads are seasonally lower than those in the Deschutes River since some of the nutrients get assimilated within Capital Lake before entering Budd Inlet. In this report, we are only presenting loads from the Deschutes River so that we can compare these with loads from other watersheds. However, the model will use the Capital Lake data to represent the inflow into Budd Inlet.

Some regions within the study area may be more sensitive to nitrogen loading than others – it is therefore constructive to separate nitrogen loads into different regions of South and Central Puget Sound, as identified in Figure 12. These regions coincide with the regions in the Puget Sound Box Model, which is another model that is being developed and used by Ecology.

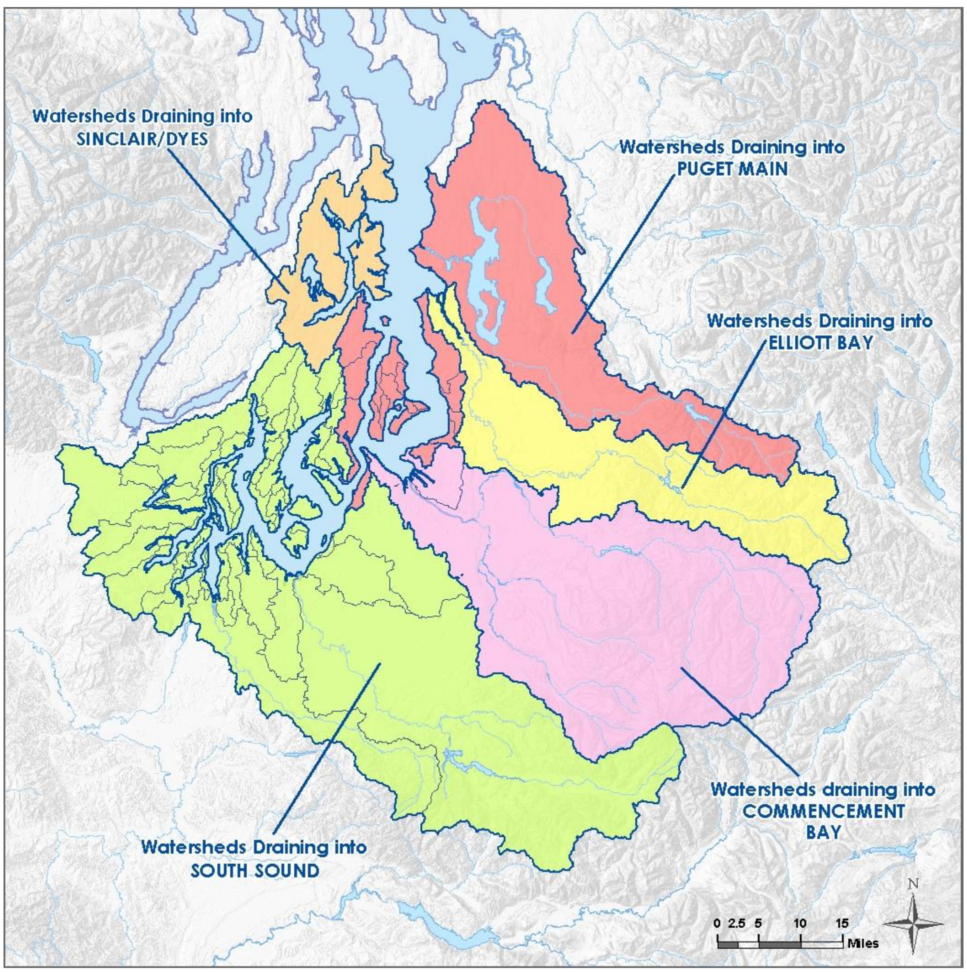

Figure 12. Watersheds in the study area color-coded by the regions in South and Central Puget Sound into which they drain

Figure 13 illustrates that total monthly nitrogen loads from South Sound are comparable in magnitude to total nitrogen loads from all the Central Puget Sound boxes (Sinclair Dyes, Puget Main, Elliott Bay, and Commencement Bay).

DIN loads follow a seasonal pattern that coincides with high and low precipitation and streamflow over the course of the year. Rivers and streams discharging between November and March contribute to 77% of the total annual DIN load from watersheds, and average DIN loads are 1.8 times higher than the annual average during this same time period.

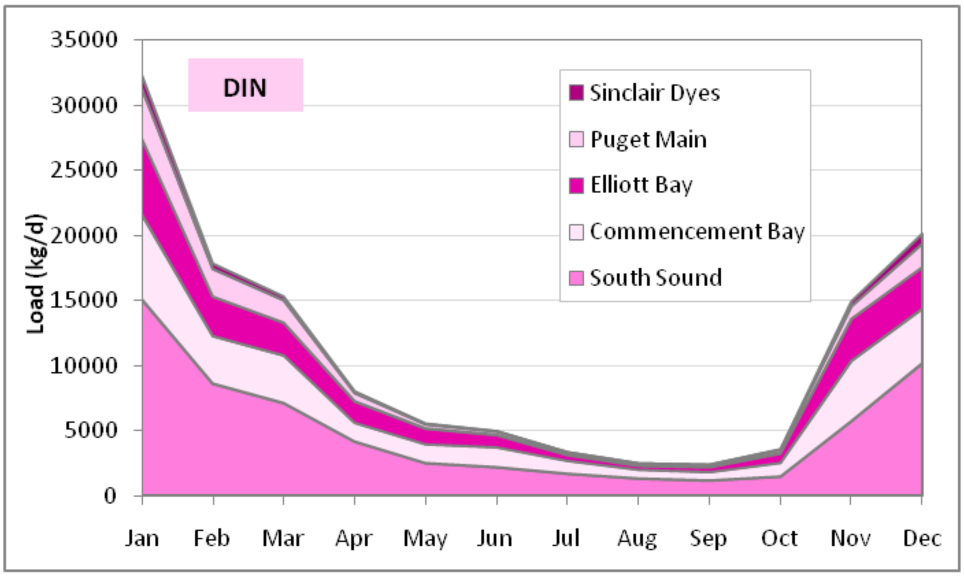

Figure 13. Mean 2006-2007 monthly nitrogen loads from watersheds totaled according to the regions in South and Central Puget Sound into which they drain.

Septic System Loads

Estimates of DIN loading from on-site septic systems in the exclusive area were provided by Whiley (2010, Appendix C). Again, these estimates are for loads from septic systems in the exclusive area, which do not include areas served by municipal wastewater treatment plants or areas that fall within monitored watersheds. Figure 14 presents a summary of the range of DIN load estimates from septic systems assuming a 10% loss in DIN from septic systems located less than 150 m from the shoreline, a 70% loss from septic systems located greater than 150 m from the shoreline, and a 58% overall loss from all regions within the exclusive area.

Figure 14. On-site septic systems DIN loading estimates from upland regions, shoreline regions, and both regions combined. Up/down bars represent 90th and 10th percentiles, boxes represent 75th and 25th percentiles, diamonds represent averages, and the black lines represent the median (adapted from Whiley 2010).

Table 8 below compares the difference in DIN loads between extrapolated areas and monitored areas to those from combined on-site septic systems (values are the 25th and 75th percentile combined values from Figure 14). The difference in load per area between extrapolated and monitored watersheds (515 kg/km^2-yr) much greater than the range of on-site septic system loads (54– 184 kg/km^2-yr) in the exclusive area. Because this difference is 2.8 to 9.5 times greater than the estimate of on-site septic system loads, we assumed that the extrapolated watershed loads adequately capture loads from on-site septic systems in the exclusive area.

Table 8. Comparison of DIN loads from monitored areas, extrapolated areas and on-site septic systems.

	DIN load (kg/d)	Relevant Area (km^2)	DIN Load: kg/ km^2-yr
Watershed Loads			
Sum of loads at monitoring locations	8859	8775	368
Sum of extrapolated loads	11580	10705	395
Difference	2722	1930	515
On-site Septic System Loads (in exclusive area)			
Septic system loads: 25th %tile	287	1930	54
Septic system loads: 75th %tile	972	1930	184

Wastewater Treatment Plant Loads

Table 9 compares mean WWTP DIN loads calculated from the multiple linear regression method with those calculated from the monthly field monitoring data. Overall subtotals and totals are comparable, though for individual WWTP, estimates derived from the regression method are slightly higher than estimates from the monthly data.

The purpose of this comparison is to illustrate that the regression method is a realistic and reasonable method of estimating loads since in most cases, these estimates are similar to measured loads.

The mean monthly data in Table 9 are different WWTP loads listed in Table 17 of the Interim Data Report (Roberts et al, 2008). The values in Table 17 were calculated for a 12-month period; however, the three months for which two years of data were available were averaged across the two years. For the purposes of comparison in this report, the annual averages are presented for WY07. Missing months are not considered in these averages. Also, plants for which three months of data are included and averaged as indicative of annual average values. These are noted with an asterisk in the table but included for completeness. WWTPs do not show as much seasonal variability as rivers and streams, but the loads may still be biased low somewhat compared to a true annual average.

The estimates derived from the regression method are our best estimate of loading several reasons: these estimates are available at a daily time step accounting for changes over the course of the year, they include loads from all WWTPs in the study area, and there are no gaps throughout the 2006-2007 study period. A complete table of summer and annual DIN loads for all WWTPs in South and Central Puget Sound is included in Appendix G.

Table 9. Comparison of DIN loads from WWTPs estimated from (1) the regression method and (2) from monthly data collected during the field monitoring period.

WWTP Name	ANNUAL DIN Load (kg/d)[1]		SEPT. 2007 DIN Load (kg/d)[2]	
	Regression	Monthly Data	Regression	Monthly Data
South Puget Sound				
Boston Harbor	2.4	2.2	1.3	1.2
Carlyon	4.1	3.8*	4.2	3.3
Chambers Creek	2162	2431	1809	2491
Fort Lewis	333	229*	337	208
Hartstene Pointe	2.5	0.3*	0.9	0.3
LOTT	154	142	87	76
Rustlewood	0.9	0.8*	0.4	0.1
Seashore Villa	0.5	0.7*	0.4	0.7
Shelton	57	48	23	13
Tamoshan	0.7	0.6	0.9	0.6
South Sound Subtotal	**2716**	**2858**	**2264**	**2794**
Central Puget Sound				
Bainbridge Kitsap Co 7	3.1	5.9*	2.1	5.9
Bremerton	351	299	149	203
Central Kitsap	457	434	427	507
Gig Harbor	38	40	23	19
Kitsap Co Kingston	3.7	5.4*	3.1	4.6
Lakota	800	753	648	578
Manchester	6.5	5.7	5.6	2.9
Midway	421	432	367	356
Miller Creek	345	241*	268	241
Port Orchard	131	122	118	108
Redondo	239	240	171	202
Salmon Creek	303	104*	193	93
Simpson Kraft	15	5.8	10.5	1.9
South King	9002	8880	8469	8376
Suquamish	7.1	18*	4.3	18
Tacoma Central	1978	1946	1918	1704
Tacoma North	385	359	376	380
Vashon	5.2	4.4*	3.0	0.1
West Point	9382	8300	9867	8847
Central Sound Subtotal	**23871**	**22195**	**23024**	**21647**
South and Central Puget Sound Total	**26587**	**25054**	**25288**	**24442**

[1]For the regressions, these values are the mean of the daily regressions for WY07 (October 2006 through September 2007). For the monthly data, the DIN loads these values are calculated from monthly grab samples collected in WY07; any missing monthly grab values are not factored into the annual averages.

[2]For the regressions, these values are the mean of September 2007 daily regressions; for the monthly data, these values are the instantaneous loads calculated from the September 2007 grab samples.

* Indicates plants only monitored for 3 months between August and September 2007, so the equivalent average is used for the annual average given that effluent loads generally do not vary significantly compared with streams.

Most WWTP had slightly lower mean annual DIN loads in 2007 than in 2006, but the difference in DIN loads between the two years was much less than the difference in watershed loads. The total mean annual DIN loads from all WWTPs in the study area were 4% lower in 2007 than in 2006. Mean annual effluent flows from WWTPs were also slightly lower in 2007, by 9%.

Figure 15 geographically illustrates median DIN concentrations for all WWTPs in the study area. Note that only those WWTPs that fall into the highest two concentration categories (i.e. the two largest dot sizes) are labeled. In addition, Figure 16 presents box and whisker plots of WWTP DIN concentrations.

Effluent from the following WWTPs have the highest median DIN concentrations of nitrogen based on monitoring data (Carlyon Beach) or regressions developed from monitoring data(Chambers Creek, Lakota, Central Kitsap and Tacoma-Central). Overall, effluent DIN concentrations are higher in for WWTPs located in Central Puget Sound relative to those located in South Puget Sound.

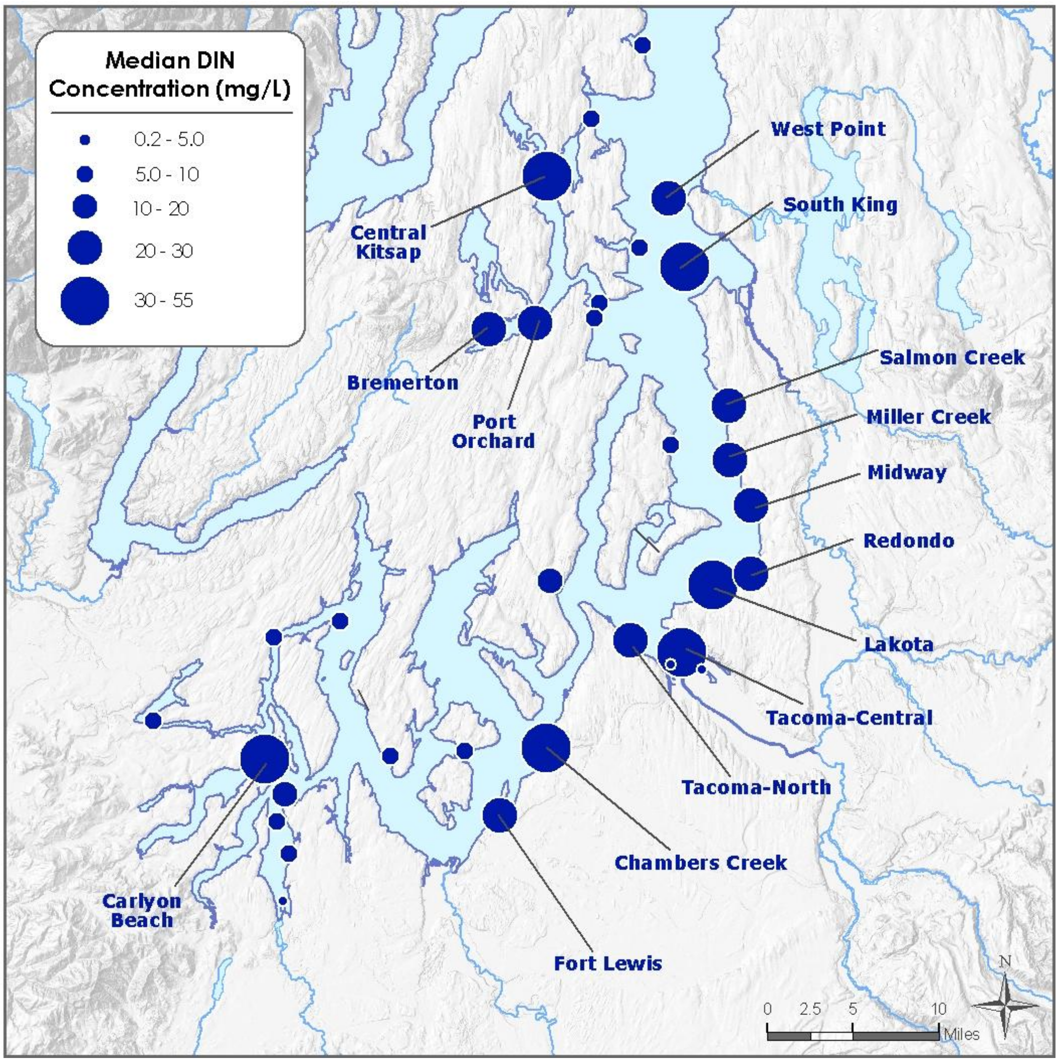

Figure 15. Median WWTP DIN concentrations for 2006 through 2007.

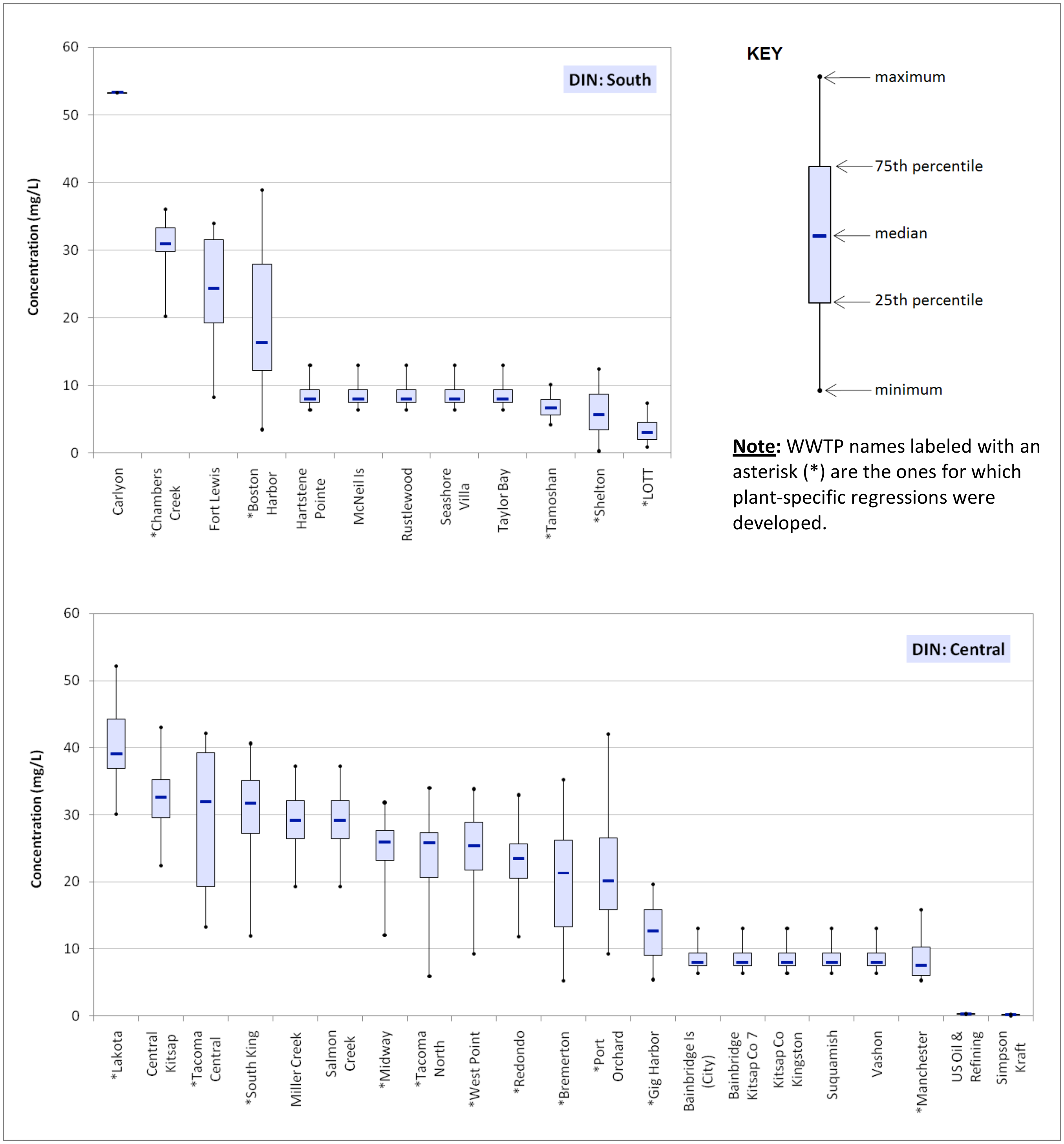

Figure 16. Box plots of DIN concentrations for 2006 – 2007 for WWTPs in South (top) and Central (bottom) Puget Sound

Since some WWTPs are larger than others in terms of the magnitude of their effluent flow, the WWTPs that have the highest nitrogen concentrations are not necessarily the same ones that have the highest nitrogen loads. For example, even though Carlyon Beach has relatively high nitrogen concentrations compared to other WWTPs in the study area, the nitrogen loading from this WWTP is relatively low. Figure 17 illustrates annual DIN loads from all WWTPs in the study area. Note that only those WWTPs that have DIN loads greater than 100 kg/d are labeled.

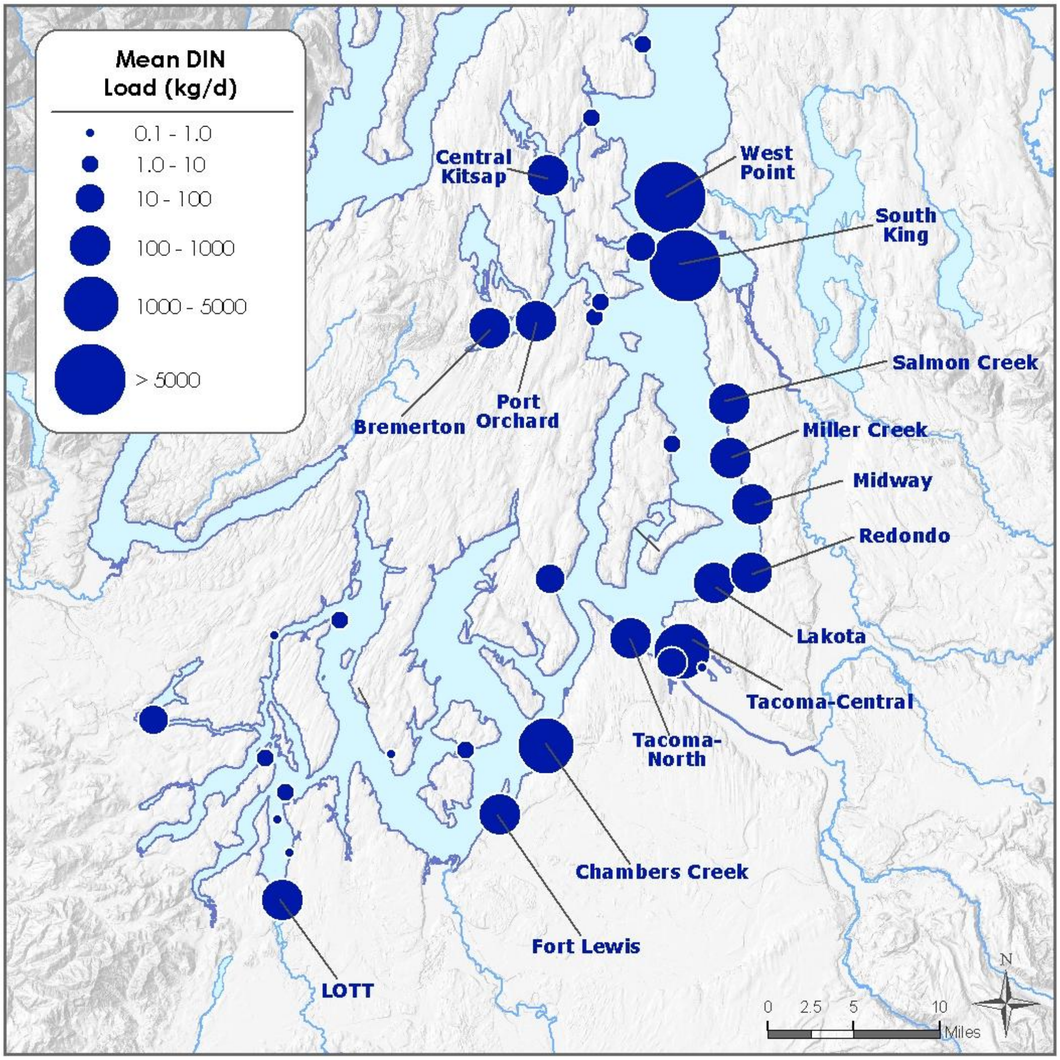

Figure 17. Mean DIN loads from WWTPs during 2006-2007

West Point and South King have the highest annual DIN loads, discharging an average of 9670 kg/d and 8810 kg/d of DIN, respectively. Chambers Creek (2140 kg/d) and Tacoma Central (2060 kg/d) are the next highest sources of DIN loading.

Monthly average nitrogen loads do not vary greatly over the course of the year (Figure 18). The twelve WWTPs located in the Puget Main region contribute to 75% of the average annual DIN load of all WWTPs in the study area. In contrast, there are also twelve WWTPs in the South Sound region, but these only contribute to 12% of the average annual DIN load of all WWTPs in the study area. This is a reflection of the higher population areas and larger urban centers served by WWTPs that discharge into Puget Main.

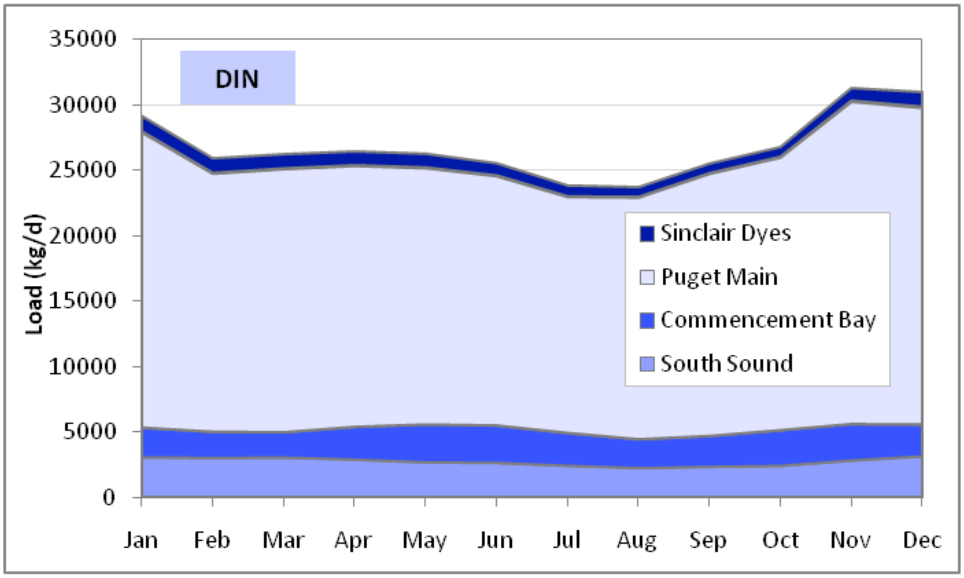

Figure 18. Mean 2006-2007 monthly DIN loads from WWTPs totaled according to the regions in South and Central Puget Sound into which they discharge effluent.

Combined Loads

In addition to nitrogen loads from rivers, WWTPs and on-site septic systems, the water quality model will also include nitrogen loading from ocean, the atmosphere, and internal sediment fluxes. This will allow us to show the effect of all these sources on DO levels. Combined loads in this portion of the report, however, focuses primarily on rivers and WWTPs.

Figure 19 compares and contrasts NH4N and NO23N concentrations for all rivers and WWTPs within the study area. These box plots were created by summarizing statistics on the *median* concentrations of NH4N and NO23N. For example, the minimum values in Figure 19 (lower bars with black dot) are the minimum of all the median concentrations of NH4N and NO23N for all rivers and WWTPs.

WWTPs have NH4N concentrations that are two to three magnitudes higher than rivers, and NO23N concentrations that are about one magnitude higher than rivers. NO23N concentrations in rivers are generally higher than NH4N concentrations, while the opposite is true for WWTPs, which have higher NH4N concentrations than NO23N concentrations.

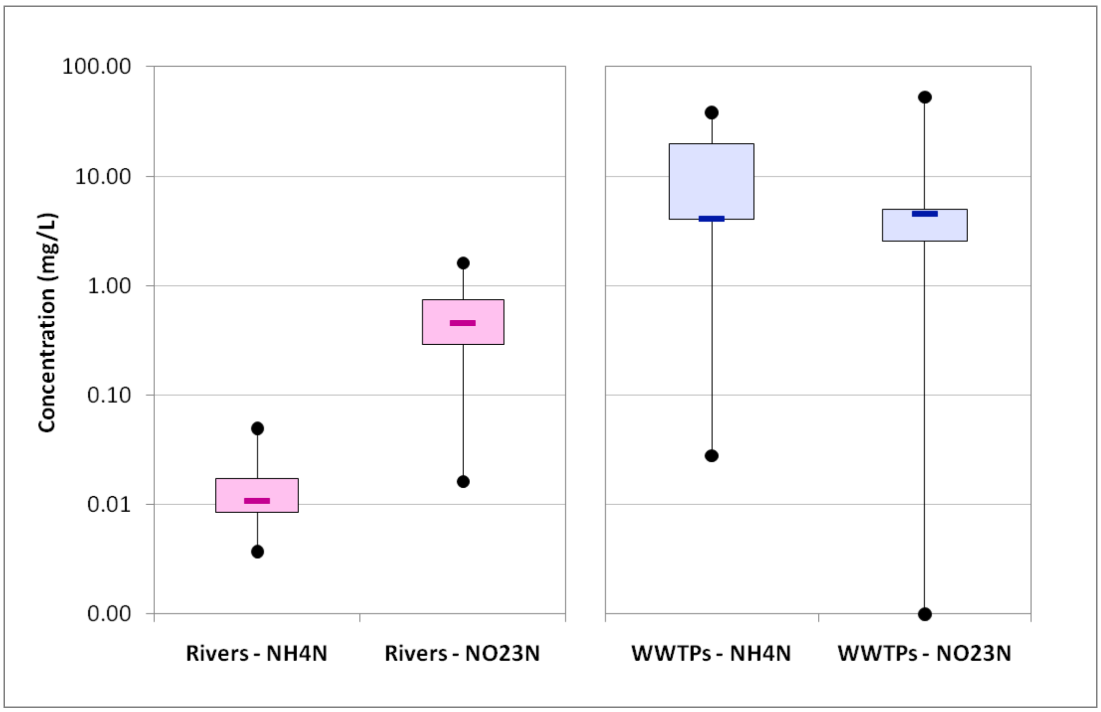

Figure 19. Box plots comparing the range of median concentrations of NH4N and NO23N across all rivers and WWTPs in the study area between 2006 and 2007 (note: the y-axis is on a logarithmic scale).

Combined average daily DIN loads for 2006-2007 from rivers and WWTPs are presented geographically in Figure 20. Watershed loads dominate in Eld, Totten, Case, and Carr Inlets. Watersheds and WWTPs discharge comparable loads in Commencement Bay and in portions of South Puget Sound east of Budd Inlet. Loads from three of the four largest rivers (Nisqually, Puyallup, Green Rivers) are comparable in magnitude to loads from Chambers Creek and Tacoma-Central. West Point and South King in Central Puget Sound have the largest DIN loads of the sources quantified to date.

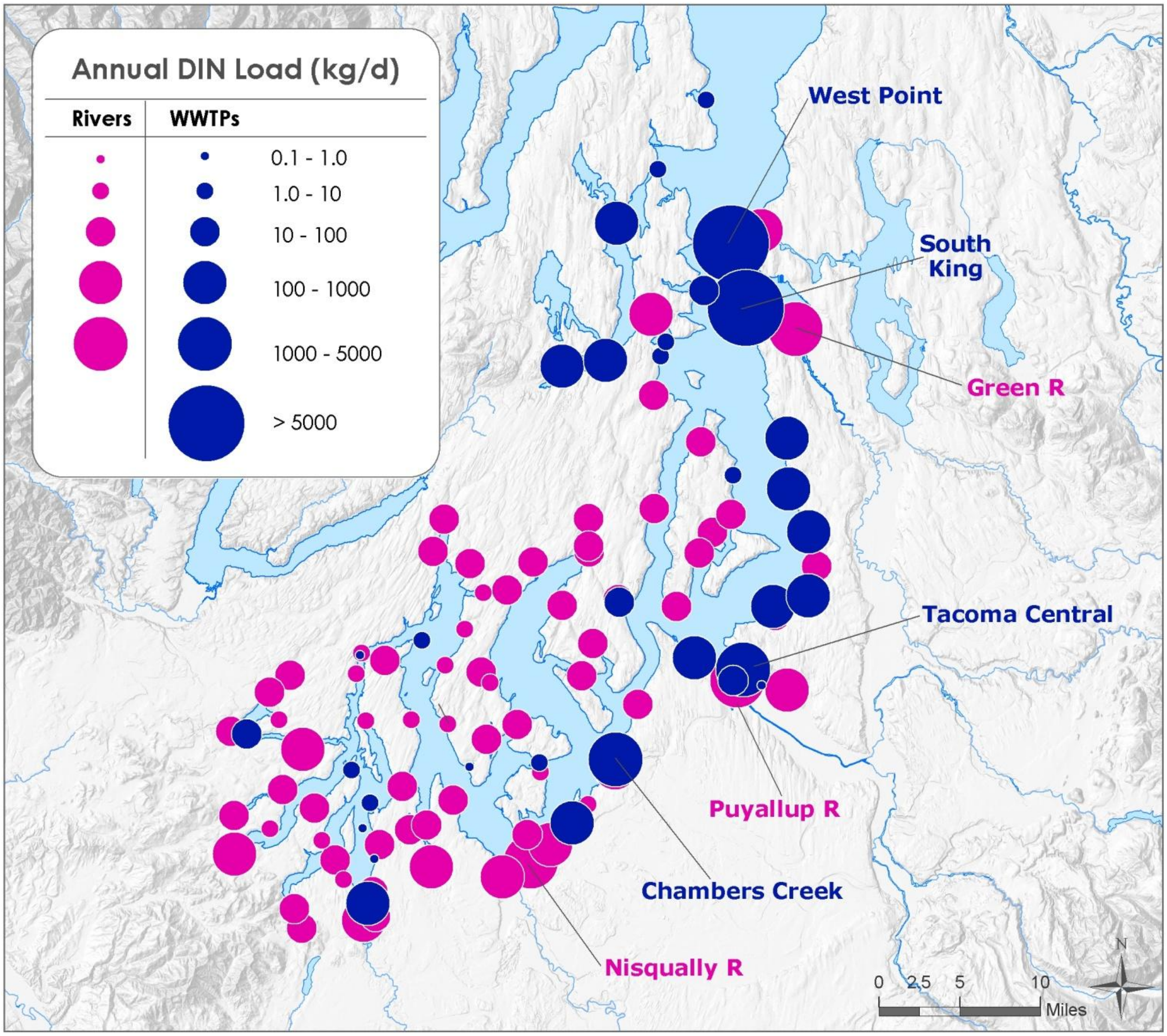

Figure 20. Average daily DIN loads from rivers and WWTPs in South and Central Puget Sound during 2006-2007.

The relative magnitude of average daily DIN loads from rivers and WWTPs changes when evaluated only during the summer (average of July, August, and September). These summer months are critical since near-bottom DO levels were generally found to be lowest in September (Roberts, et al., 2008). The months preceding these low DO conditions are therefore an important time period.

As illustrated in Figure 21, DIN loads from rivers drop during the summer because of lower streamflows and less precipitation; all DIN loads from rivers during the summer months are below 1000 kg/d. Although WWTP DIN loads during the summer are also slightly lower than during the rest of the year, they still dominate. West Point and South King are the two largest single sources of DIN, followed by Chambers Creek and Tacoma-Central.

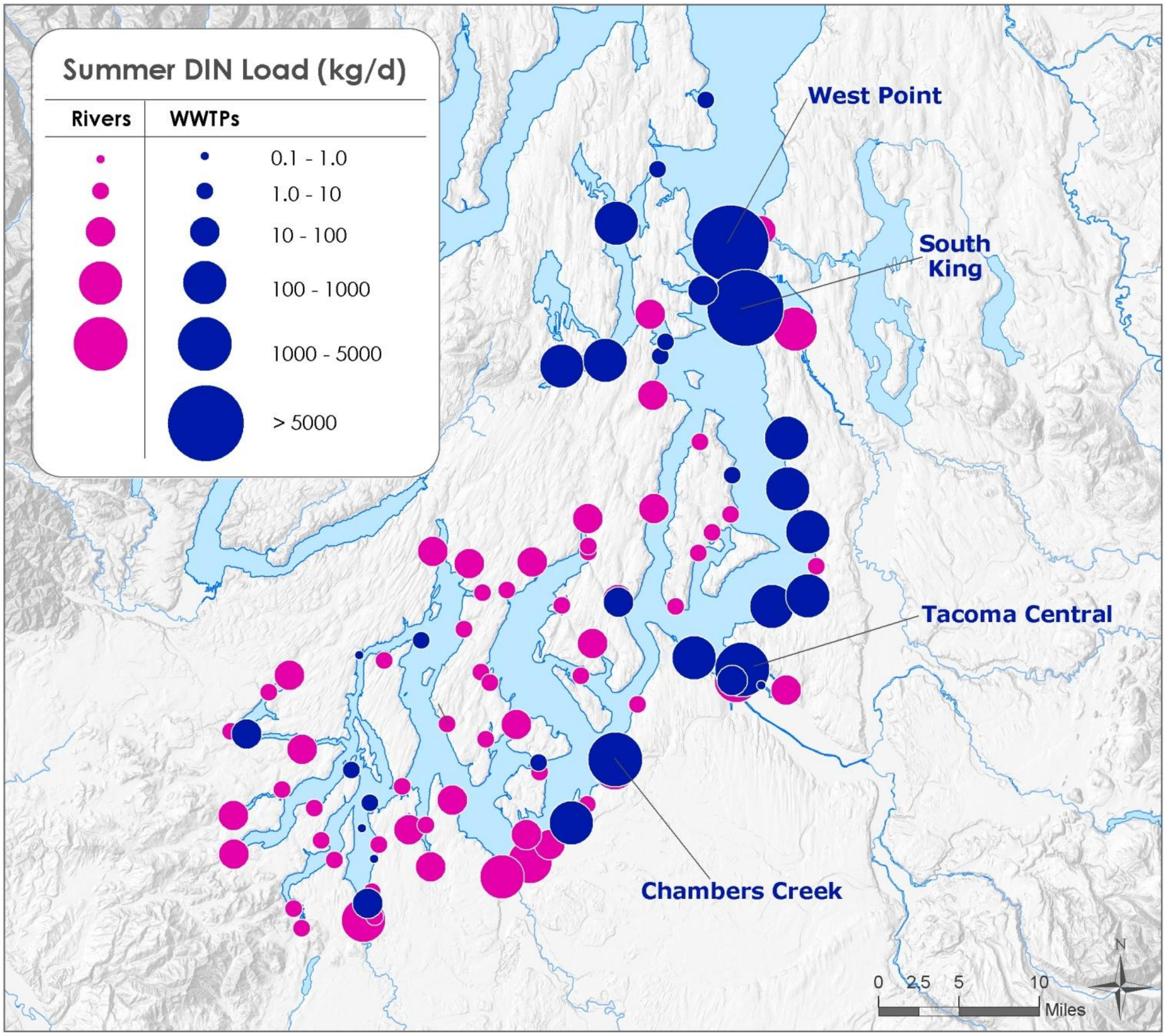

Figure 21. Summer (average July, August and September during 2006-2007) DIN loads from rivers and WWTPs in South and Central Puget Sound.

Daily river DIN loads are more variable than daily WWTP DIN loads since river loads reflect variability in river flows, which change with seasons (Figure 22). In South Puget Sound, daily river DIN loads are much greater than WWTP DIN loads during the months of November through April, but the two sources are comparable in magnitude during the drier months (Figure 22, top). In central Puget Sound, however, WWTP DIN loads are greater than river DIN loads throughout the year except during a few large storm events during the winter months (Figure 22, bottom).

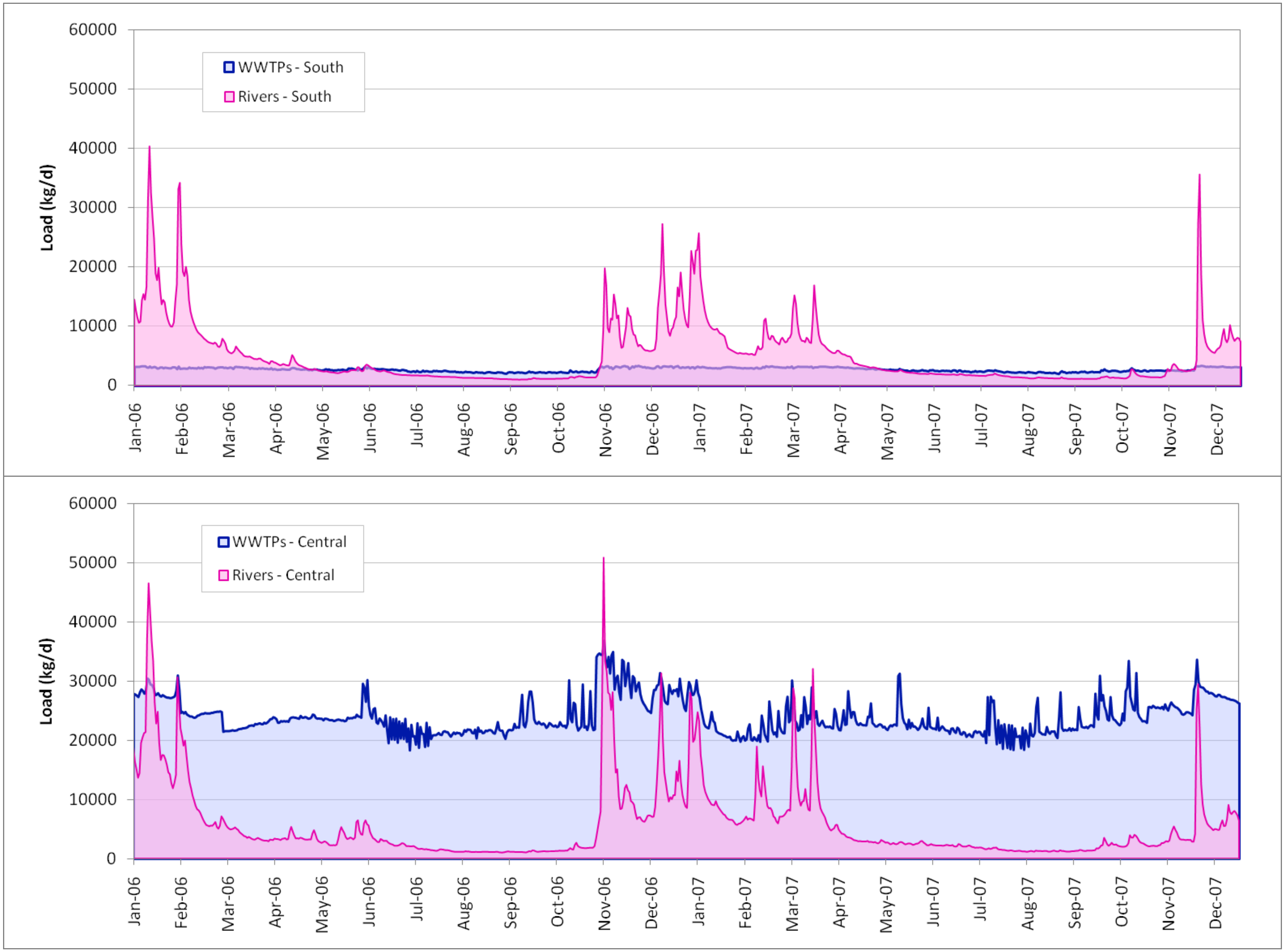

Figure 22. Daily DIN loads from rivers and WWTPs in South (top) and Central (bottom) Puget Sound from 2006-2007

Figure 23 presents the 7-day average of daily DIN loads from rivers and WWTPs in South and Central Puget Sound, stacked on top of each other. The 7-day average of daily DIN loads (rivers plus WWTPs) into South and Central Puget Sound ranges from approximately 25 – 95 metric tons/day, and 64-89% of this load is from Central Puget Sound.

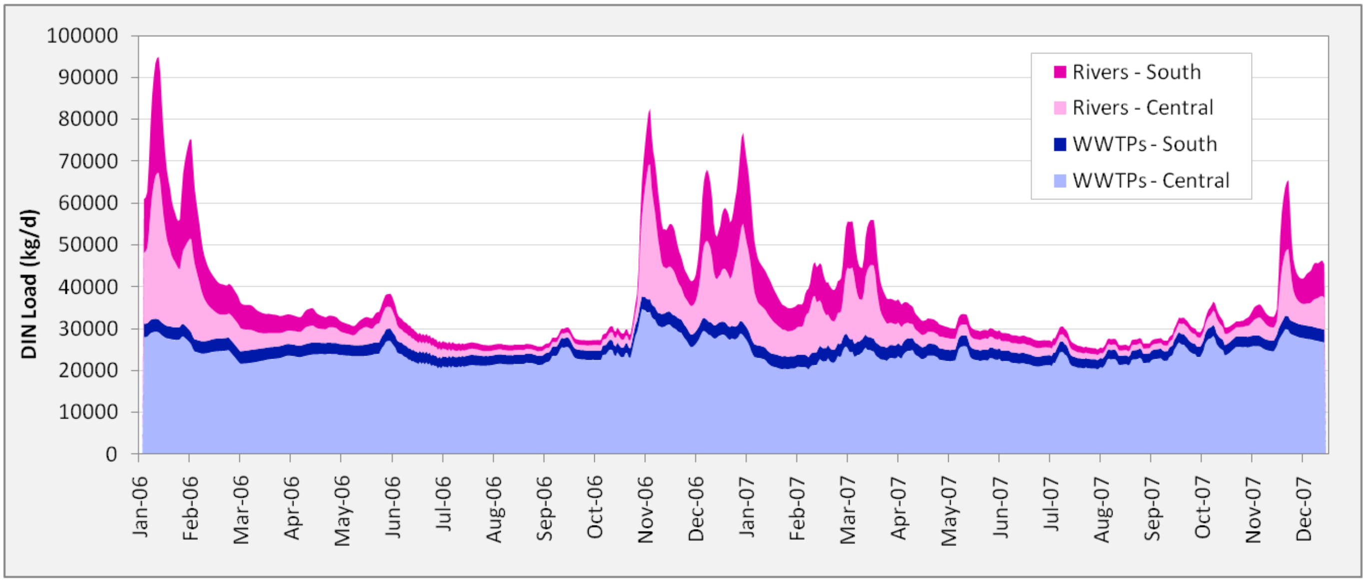

Figure 23. Seven-day average of daily DIN loads from rivers and WWTPs in South and Central Puget Sound during 2006-2007.

Figure 24 summarizes the relative DIN loads from rivers and WWTPs into South and Central Puget Sound on an annual basis and during the summer.

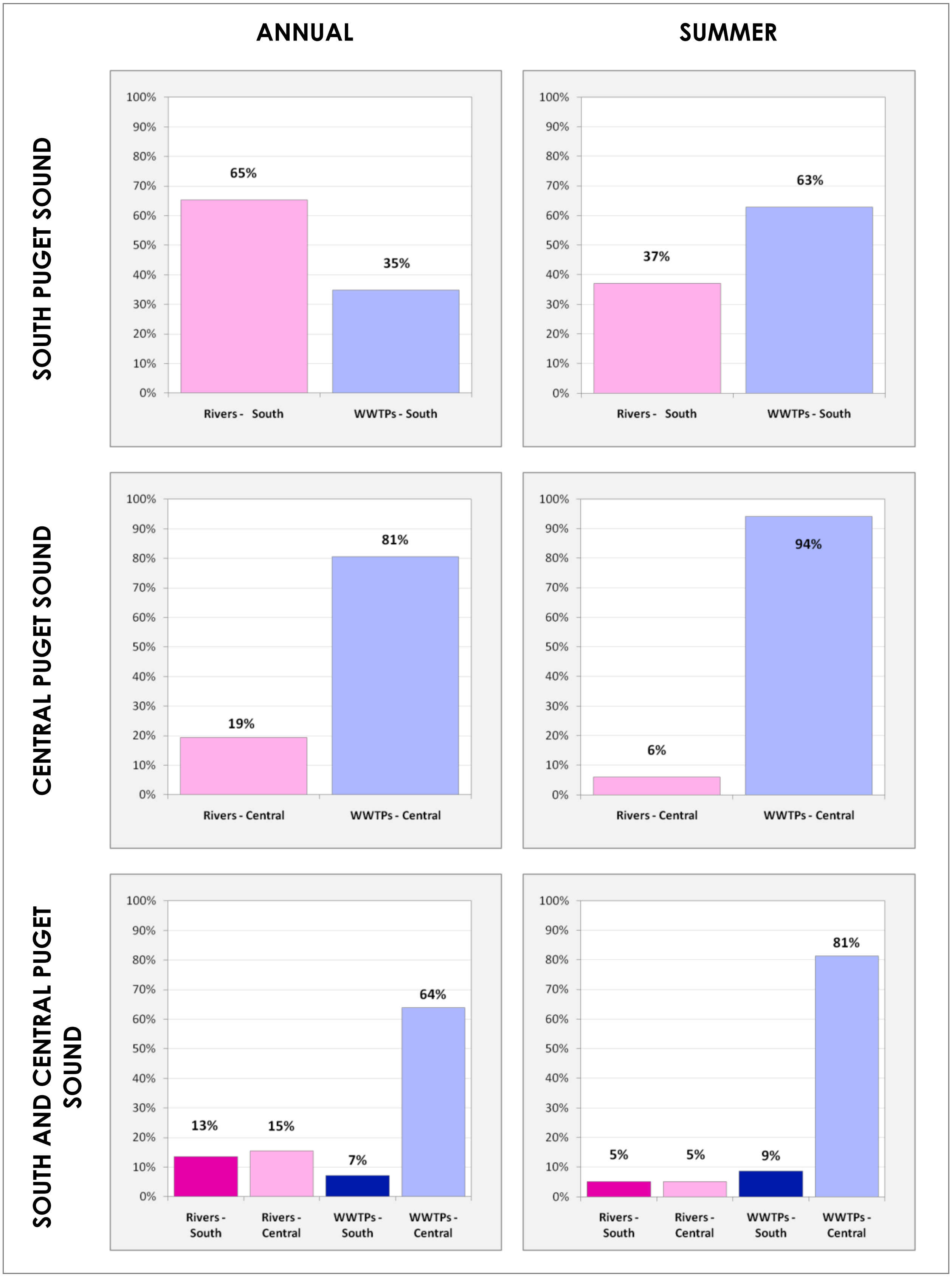

Figure 24. Pie charts comparing the relative contributions of DIN loads from rivers and WWTPs in South and Central Puget Sound on an annual basis (2006-2007) and during the summer.

In South Puget Sound, rivers have higher DIN loads (65%) than WWTPs (35%) on an annual basis (Figure 24, top left). The ratio of river to WWTP load flips during the summer when rivers loads are low due to lower flows, and they contribute to 37% of the load while WWTPs contribute 63% (Figure 24, top right).

In Central Puget Sound, WWTPs contribute 81% of the annual average DIN load (Figure 24, center left) and 94% of the average summer DIN load (Figure 24, center right). When DIN loads from rivers in South and Central Puget Sound are combined, rivers in South Puget Sound contribute almost the same share of DIN loads as rivers in Central Puget Sound. Of the total combined loads from South and Central Puget Sound, WWTPs contribute 71% of the load on annual basis, and 90% of the load during the summer.

We can also normalize these loads by the total land area within our study (sum of the areas of all South plus Central Puget Sound watersheds) to get load per unit area: the annual average river DIN loads per unit area from rivers is 370 kg/km^2-yr, while the combined load per unit area from rivers and wastewater treatment plants is 1280 kg/km^2-yr.

Overall, DIN loads from rivers and WWTPs in Central Puget Sound are three and half times greater than DIN loads from South Puget Sound (Figure 25).

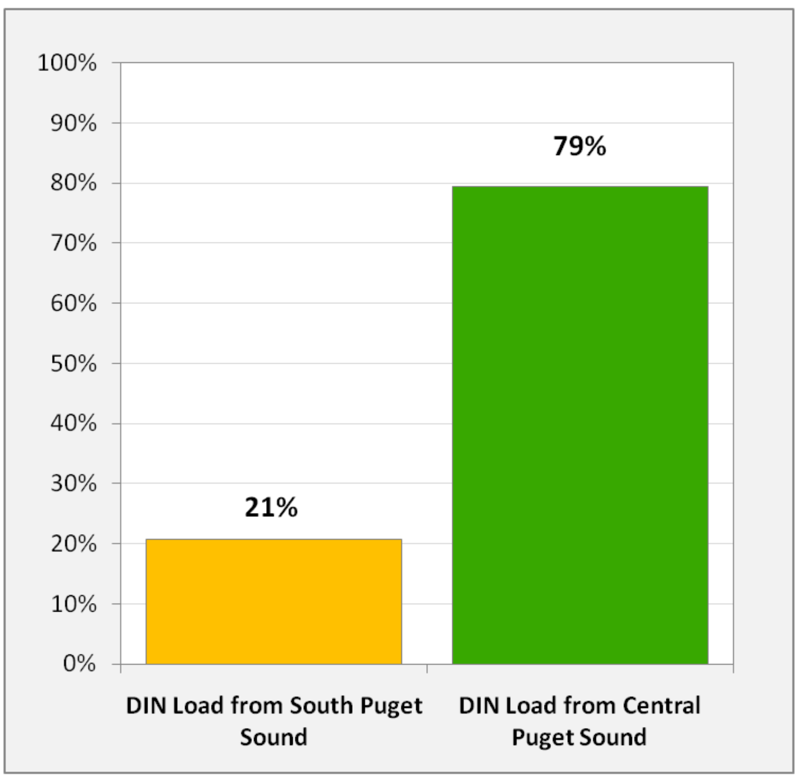

Figure 25. Annual DIN loads from rivers and WWTPs in South vs. Central Puget Sound.

Atmospheric deposition of DIN to the surface waters of South and Central Puget Sound were estimated by Roberts et al.(2008), and make up only 1% of the annual DIN loads in the study area (Figure 26). Note that loads from on-site septic systems are included in the 'Rivers' share of the pie chart since these extrapolated loads were found to be adequate to capture loads from on-site septic systems.

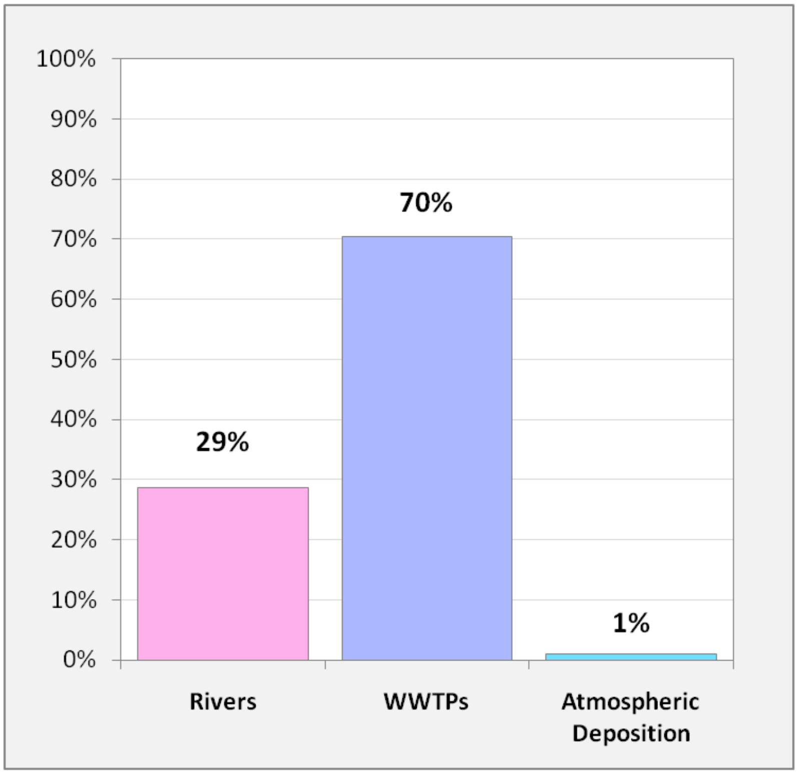

Figure 26. Annual DIN loads from rivers, WWTPs, on-site septic systems and the atmosphere in South and Central Puget Sound.

The following information will be added to the final report:
An additional source of DIN is from groundwater discharging directly into the marine waters of South and Central Puget Sound. The volume of direct groundwater discharge into South and Central Puget Sound is ______ m^3/d. Using a groundwater DIN concentration of ______ mg/L, this results in a total annual load of ______ kg/d of DIN from groundwater.

Natural Conditions for Nutrient Loads

Table 10 summarizes data and information from the various sources consulted to establish natural conditions for rivers and streams in South and Central Puget Sound.

Table 10. Nutrient result summary for rivers and streams in South and Central Puget Sound and nearby reference areas.

	Statistic	TPN (mg/L)	NO23N (mg/L)	NH4N (mg/L)	TP (mg/L)	OP (mg/L)	Notes
Recent Ambient Data (within model domain)							
Puget South	10%ile of recent data	0.165	0.116	0.01	0.013	0.007	1
Commencement Bay	10%ile of recent data	0.109	0.071	0.01	0.032	0.012	1
Puget Main	10%ile of recent data	0.151	0.112	0.01	0.006	0.005	1
Elliott Bay	10%ile of recent data	0.300	0.218	0.01	0.021	0.009	1
	Median for this method:	0.158	0.114	0.010	0.017	0.008	
Recent Ambient Data (near model domain)							
Hood Canal	10%ile of recent data	0.025	0.011	0.01	0.004	0.003	1
SJF/SOG	10%ile of recent data	0.025	0.010	0.01	0.006	0.003	1
Whidbey	10%ile of recent data	0.089	0.051	0.01	0.010	0.003	1
	Median for this method:	0.025	0.011	0.010	0.006	0.003	
Historical Ambient Data (less developed watersheds)							
Nisqually	Median of historic data	--	0.14	--	--	--	2
Lower Skagit	Median of historic data	--	0.3	0.04	0.02	0.01	2
Upper Skagit	Median of historic data	--	0.2	0.02	0.01	0.01	2
	Median for this method:	--	0.2	0.03	0.015	0.01	
Recent Ambient Data (less developed watersheds)							
Nisqually	Median of recent data	0.203	0.163	0.01	0.025	0.009	2b
Lower Skagit	Median of recent data	0.141	0.113	0.01	0.019	0.004	2b
Upper Skagit	Median of recent data	0.079	0.062	0.01	0.006	0.003	2b
	Median for this method:	0.141	0.113	0.010	0.019	0.004	
Atmospheric (rainfall) data							
Olympics Only	Median of recent data	--	0.11	0.01	--	--	3
All 4 Stations	Median of recent data	--	0.23	0.02	--	--	3
Toxics in Surface Runoff							
Forested basins	Median of stormwater data	0.303	0.228	0.005	0.024	0.006	4
Forested basins	Median of baseflow data	0.157	0.089	0.005	0.015	0.003	4
	Median for this method:	0.230	0.159	0.005	0.020	0.005	
Hood Canal Dissolved Oxygen Program							
Forested basins	Unclear	--	0.070	--	--	--	5

Notes: General: Non-detects, primarily for ammonia, are represented at the detection limit.

1. These are the 10%ile of recent data collected at several of Ecology's ambient monitoring stations, aggregated into different regions of Puget Sound. For all parameters except TP, these are the 10%tile of data collected between WY 2002 and WY 2009. For TP, data are from WY 2007 and WY 2009 since there was a change in lab methods in 2003 and in again 2007 which did not allow us to pool the older data with the newer data.

2. Historical ambient monitoring data collected by Ecology were used. The Nisqually, Lower and Upper Skagit Rivers were chosen because these watersheds have less development than other watersheds in Puget Sound, and are therefore good reference sites for natural conditions. Data for the following years were used for each parameter: NO23N: WY 1960-1970, NH4N and OP: WY 1976-1979, TP: WY 1975-1979. Dashes ("--") mean that data were not available.

2b. The most recent ambient monitoring data from Ecology are for the period October 2008 through September 2009.

3. Atmospheric concentration data (i.e. rainfall) for WY 2002-2009 were downloaded from the National Atmospheric Deposition Program. There are four stations located in Western Washington: one in the Olympics, two near Mt. Rainier and one in the North Cascades. The station located in the Olympics, however, is upwind from the other stations and least influenced affected by local sources of nutrients, therefore serving has a better reference station for natural conditions.

4. Nutrient concentrations in surface runoff (baseflow and stormwater events) were measured by Herrera Environmental Consultants as part of the Puget Sound Toxics Loading project (www.ecy.wa.gov/biblio/0910052.html). The values here are the median of data collected from predominantly forested sub-basins in the Puyallup and Snohomish watersheds.

5. The Hood Canal Dissolved Oxygen Program has estimated this value as the natural background DIN concentrations for Hood Canal as part of their study (Steinberg et al., 2010). The value is intended to represent baseline stream water DIN concentrations.

Nutrient concentrations generally reflect development levels, with lower values in less developed watersheds such as Hood Canal and higher in more developed watersheds such as Elliott Bay. It is also interesting to note that recent median concentrations of nitrogen in Skagit River are generally *lower* than 1960s and 1970s median concentrations. Although the exact reason for this is not known, it may be a combination of factors including improved lab analysis methods and higher historical contributions from nonpoint sources of nitrogen in the 1960s and 1970s.

Nitrogen concentrations from the atmospheric station in the Olympics (0.11 mg/L NO23N) are lower than those for all four stations pooled together (0.23 mg/L NO23N). The higher levels at the other stations may reflect local atmospheric nitrogen sources within the Puget Lowland, which influence stations other than the Olympics.

Median concentrations of nutrients in surface runoff (estimated as part of the Puget Sound Toxics Loading Project) for baseflow conditions are generally lower than the 10th percentile of ambient data, while concentrations for stormwater conditions are generally higher than the 10th percentile of ambient data.

Because Table 10 includes multiple sites for each method, the number of sites would influence the result if the individual sites were weighted equally. Instead, medians of each method were calculated, and a subset of these methods was then selected to calculate natural condition concentrations. The final set of selected methods and the median values from each of these methods are presented in Table 11. The overall median is close to the 10th percentile of recent ambient data within the model domain, and these overall medians were used to represent natural conditions.

Table 11. Summary medians of the meta-analysis.

STATISTIC	TPN (mg/L)	NO23N (mg/L)	NH4N (mg/L)	TP (mg/L)	OP (mg/L)
Median of 10%ile of recent ambient data (within model domain)	0.158	0.114	0.010	0.017	0.008
Median of median historic ambient data (less developed watersheds)	0.295*	0.200	0.030	0.015	0.010
Median of Olympics atmospheric rainfall data	0.151*	0.108	0.010	--	--
Median of surface runoff in forested basins	0.230	0.159	0.005	0.020	0.005
Hood Canal Dissolved Oxygen Program	0.090*	0.070	--	--	--
OVERALL MEDIAN	**0.158**	**0.114**	**0.010**	**0.017**	**0.008**

* Where TPN data were not available, the estimate was based on a relationship developed from Table 10, where DIN = 78% of TPN on average.

Using the overall median concentrations in Table 11, the natural DIN concentration is:

$$Natural\ DIN\ Concentration = NO23N\ concentration + NH4N\ concentration$$

$$= 0.114\ mg/L + \ 0.010\ mg/L = \mathbf{0.124\ mg/L}$$

Multiplying the above DIN concentration (0.124 mg/L) by the daily streamflow for all rivers and streams in South and Central Puget Sound (i.e. for the entire watershed, not just monitored rivers) provides an estimate of nutrient loads under natural conditions. We calculated natural DIN loads under natural conditions for South and Central Puget Sound as follows:

$$DIN\ Load\ \left(\frac{kg}{day}\right) = \frac{\sum(DIN\ Concentration * Daily\ Sound\ wide\ flows\ 2006\ \&\ 2007)}{730\ days}$$

Under natural conditions, the DIN load was found to be 1410 kg/d for South Puget Sound and 2415 kg/d for Central Puget Sound, adding up to a total of 3825 kg/d of DIN. These loads vary seasonally primarily due to seasonal flow fluctuations.

Discussion

Rivers and WWTPs

Rivers and WWTPs discharge an annual average total of 10,890 kg/d and 26,750 kg/d of DIN, respectively, within the study area; a total of 37,650 kg/d. On an annual average basis, DIN loads from rivers tend to dominate in South Puget Sound, while DIN loads from WWTPs tend to dominate in Central Puget Sound. Overall, loads from Central Puget Sound are much greater than those from South Puget Sound, and loads from WWTPs are greater than loads from rivers.

WWTPs in Central Puget Sound serve higher population centers and larger service areas than those in South Puget Sound. These WWTPs therefore treat a much larger volume of wastewater than those in South Puget Sound. Even if treatment processes at these plants lowers the *concentration* of nitrogen in the effluent, *loads* are still high since effluent flows are high; higher flows result in higher loads. Of all the WWTPs in the study area, West Point and South King in Central Puget Sound contribute the highest loads (> 5000 kg/d). Overall, the load summaries for WWTPs determined from the regression approach are comparable to those from the monthly grab samples.

Rivers exhibit a seasonal pattern in nitrogen loading over the course of the year because of variations in flow that are a response to variations in precipitation. Though the largest rivers do not necessarily have the highest nitrogen concentrations, they do tend to have larger nitrogen loads relative to the rest of the rivers and streams in the study area. The four largest rivers in the study contribute the largest watershed DIN loads in the following order: Puyallup, Green Nisqually, and Deschutes. The former two are located in Central Puget Sound while the latter two are located in South Puget Sound. These river loads, however, also include loads from WWTPs and septic systems located upstream of monitoring locations. Overall, the load summaries for rivers determined from the regression approach are comparable to those determined from the monthly grab samples.

Septic System Loads

Estimates of annual DIN loads from on-site septic system loads located within the exclusive area (outside of monitored catchments and outside of municipal wastewater service areas) are two orders of magnitude lower than the all river and WWTP loads (the 25^{th} to 75^{th} percentile of these estimates range from 290 – 970 kg/d) within the study area.

When we extrapolated loads from monitoring locations to unmonitored locations, we found that this extrapolation adequately accounted for loads from on-site septic system located within the exclusive area.

Natural Conditions

River and stream nutrient levels reflect the overall population and development levels within the watersheds. Using several methods, including less developed reference sites and statistical analyses, we identified natural condition concentrations for nitrogen and phosphorus. These lower concentrations translate to lower loads under natural conditions. Table 12 compares DIN loads from the 2006-2007 data with the natural DIN loads that were estimated from the meta-analysis.

Table 12. Comparison of natural and 2006-2007 average annual DIN loads from rivers and WWTPs into South and Central Puget Sound.

	Average Annual DIN Load (kg/d)		
	Natural Conditions	**2006-2007 Rivers Only**	**2006-2007 Rivers + WWTPs**
South Puget Sound	1410	5080	7785
Central Puget Sound	2415	5810	29860
South + Central Puget Sound	3825	10890	37645

Current average annual DIN loads (2006-2007) from rivers and streams are higher than those established for natural conditions. This analysis indicates that current loads from rivers and streams are 3.6 times higher than natural conditions for South Puget Sound, 2.4 times higher for Central Puget Sound, and 2.9 higher overall. When we include WWTPs, current loads are 6 times higher than natural conditions for South Puget Sound, 12 times higher for Central Puget Sound, and 10 times higher overall.

Conclusions

Several conclusions are supported by the results presented in this report.

DIN loads from Central Puget Sound are 3.8 times greater than the DIN loads from South Puget Sound. Of these loads, WWTPs produce 71% of the annual DIN load compared to rivers. While river loads vary with season, WWTP loads are more constant throughout the year. 77% of the total annual DIN loading from rivers occurs during the wetter months of November through March. In contrast, WWTPs loads contribute to a greater proportion to the summer DIN load than the winter DIN load.

The same nutrient hot-spots are identified using regression-derived estimates as were identified from the monthly field monitoring data which were presented in the Interim Data Report (Roberts, et al., 2008). For rivers, concentration hot spots include watersheds draining into the southern inlets of South Puget Sound. Even though absolute nutrient loads from watersheds in South Puget Sound are slightly lower than those from Central Puget Sound, *relative* nutrient loads (relative to the size of the watershed) in a few watersheds in South Puget Sound are higher than those in Central Puget Sound.

For WWTPs, those located in Central Puget Sound dominate in terms of loading contributions. This is largely a reflection of the larger populations served by these WWTPs. WWTPs serving smaller populations tend to contribute smaller loads.

Current nutrient loads from rivers and streams, which include wastewater treatment plants discharging to freshwater, are 2.8 times natural condition loads to South and Central Puget Sound. When we include rivers and all WWTPs, including those discharging to marine waters, current loads are 10 times natural condition loads. The difference between current and natural loads reflects the influence of anthropogenic sources of nutrients, including changes in land use and development, increases in population, and loads from WWTPs.

The load estimates presented in this report are critical to evaluating and analyzing the effect of these loads on the water quality of South and Central Puget Sound. These estimates not only contribute to the ongoing modeling effort, but also allow us to compare the relative magnitudes and sources of loads, communicate results, and further our understanding of South Puget Sound water quality.

Recommendations

The daily nutrient loading data that we have developed for 2006-2007 provides a more comprehensive understanding of the relative magnitudes and sources of nutrient loads into South and Central Puget Sound than we would have with just the monthly field monitoring data. The daily concentration and load estimates follow similar patterns as those found in the field monitoring data, because the method is based on the data.

In addition, we now have more detailed information on nutrient loading than what the monthly data by itself can provide. For example, one or two months of data were missing for a few WWTPs where 24-hour composite samples were not collected, but the multiple linear regression is able to fill these gaps in the data using plant-specific patterns. Since several smaller watersheds, drainage areas, and streams were not monitored at all, we now have an estimate of nitrogen loading from these watersheds.

We currently have an estimate of DIN loads from on-site septic systems located within the exclusive area (outside of monitored locations and outside of municipal wastewater services areas). For future analysis, it might be useful to also have an estimate of DIN loads from on-site septic systems within monitored catchments – this would allow us to determine the proportion of current watershed loads that are sourced by on-site septic systems.

In terms of future monitoring, it would be useful to compare the daily concentration and load estimates derived from the regression approach to continuous daily observed data. Ecology is currently conducting a pilot project on the Deschutes River which involves automatic nitrate sampling every 15 minutes (Sackmann, 2009). Once Ecology has sufficient data from this project, it would be instructive to use the regression approach to predict nitrogen concentrations for the same time period and compare the two predicted and observed data at a daily interval.

Even though the multiple linear regression approach is an estimate or prediction, it is important to note that this method is directly based on monitoring data from watersheds that cover 82% of the total study area, and from WWTPs that contribute 89% of all the WWTP discharges the study area. The models that are currently being developed should also be used to specifically assess the impact of loading from those watersheds and WWTPs where site-specific regressions were not developed. This will allow us to determine whether the model is sensitive to these particular sources of nitrogen, and if so, assess the impact of our estimates for these sources on South Sound water quality. Since few data were available for the Lake Washington and Sinclair/Dyes Inlet watersheds, this might be another target for a more detailed analysis during the modeling phase.

Now that we have a better understanding of the magnitudes and sources of nutrient loads, we can assess the impact of these nutrient loads on water quality and DO levels in South Puget Sound. This is a major goal of the modeling effort which is currently underway.

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Appendices

Appendix A. Glossary, Acronyms, and Abbreviations

Glossary

Anthropogenic: Human-caused.

National Pollutant Discharge Elimination System (NPDES): National program for issuing, modifying, revoking and reissuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements under the Clean Water Act. The NPDES program regulates discharges from wastewater treatment plants, large factories, and other facilities that use, process, and discharge water back into lakes, streams, rivers, bays, and oceans.

Nonpoint source: Pollution that enters any waters of the state from any dispersed land-based or water-based activities, including but not limited to atmospheric deposition, surface-water runoff from agricultural lands, urban areas, or forest lands, subsurface or underground sources, or discharges from boats or marine vessels not otherwise regulated under the NPDES program. Generally, any unconfined and diffuse source of contamination. Legally, any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act.

Parameter: Water quality constituent being measured (analyte). A physical, chemical, or biological property whose values determine environmental characteristics or behavior.

Point source: Sources of pollution that discharge at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites that clear more than 5 acres of land.

Stormwater: The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snow melt. Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

303(d) list: Section 303(d) of the federal Clean Water Act requires Washington State to periodically prepare a list of all surface waters in the state for which beneficial uses of the water – such as for drinking, recreation, aquatic habitat, and industrial use – are impaired by pollutants. These are water quality-limited estuaries, lakes, and streams that fall short of state surface water quality standards and are not expected to improve within the next two years.

10th percentile: A statistical number obtained from a distribution of a data set, above which 90% of the data exists and below which 10% of the data exists.

25th percentile: A statistical number obtained from a distribution of a data set, above which 70% of the data exists and below which 25% of the data exists.

75th percentile: A statistical number obtained from a distribution of a data set, above which 25% of the data exists and below which 75% of the data exists.

90th percentile: A statistical number obtained from a distribution of a data set, above which 10% of the data exists and below which 90% of the data exists.

Acronyms and Abbreviations

Following are acronyms and abbreviations used frequently in this report.

Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
GIS	Geographic Information System software
MEL	Manchester Environmental Laboratory
NPDES	(See Glossary above)
SOP	Standard operating procedures
USGS	U.S. Geological Survey
WRIA	Water Resources Inventory Area
WWTP	Wastewater treatment plant

Units of Measurement

cms	cubic meters per second, a unit of flow.
kg	kilograms, a unit of mass equal to 1,000 grams.
kg/d	kilograms per day
km	kilometer, a unit of length equal to 1,000 meters.
m	meter
mg	milligrams
mg/L	milligrams per liter, a unit of concentration
mgd	million gallons per day
mi	mile, a unit of length equal to 1,609 meters.

Appendix B. Observed and Predicted Flows

Figures B-1 and B-2 compare predicted and observed flows at creeks which did not have USGS gages located within their watersheds, but where instantaneous flow measurements were taken monthly for 15 months.

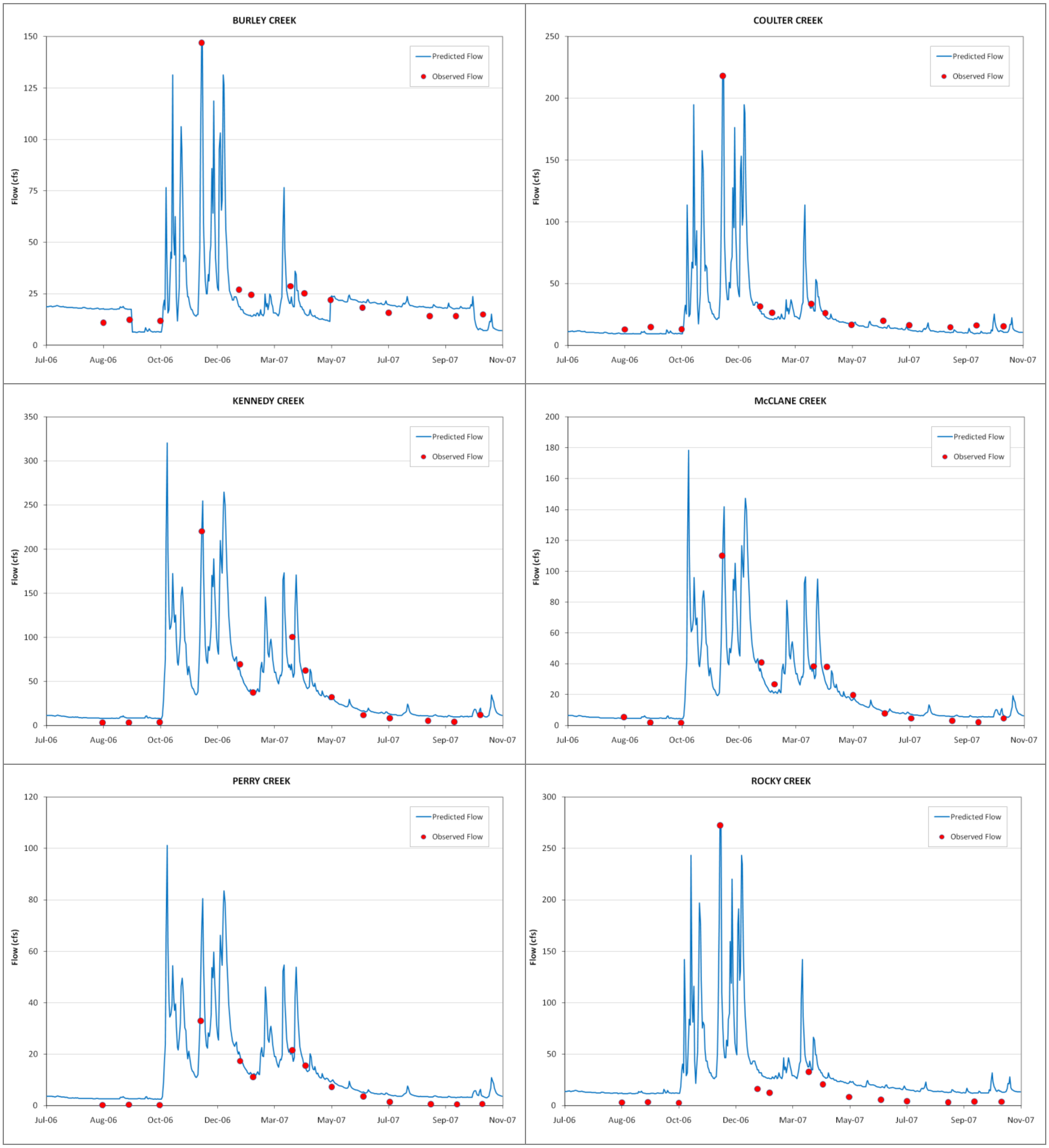

Figure B-1. Predicted and observed flows on creeks where 15 months of data were collected between July 2006 and October 2007.

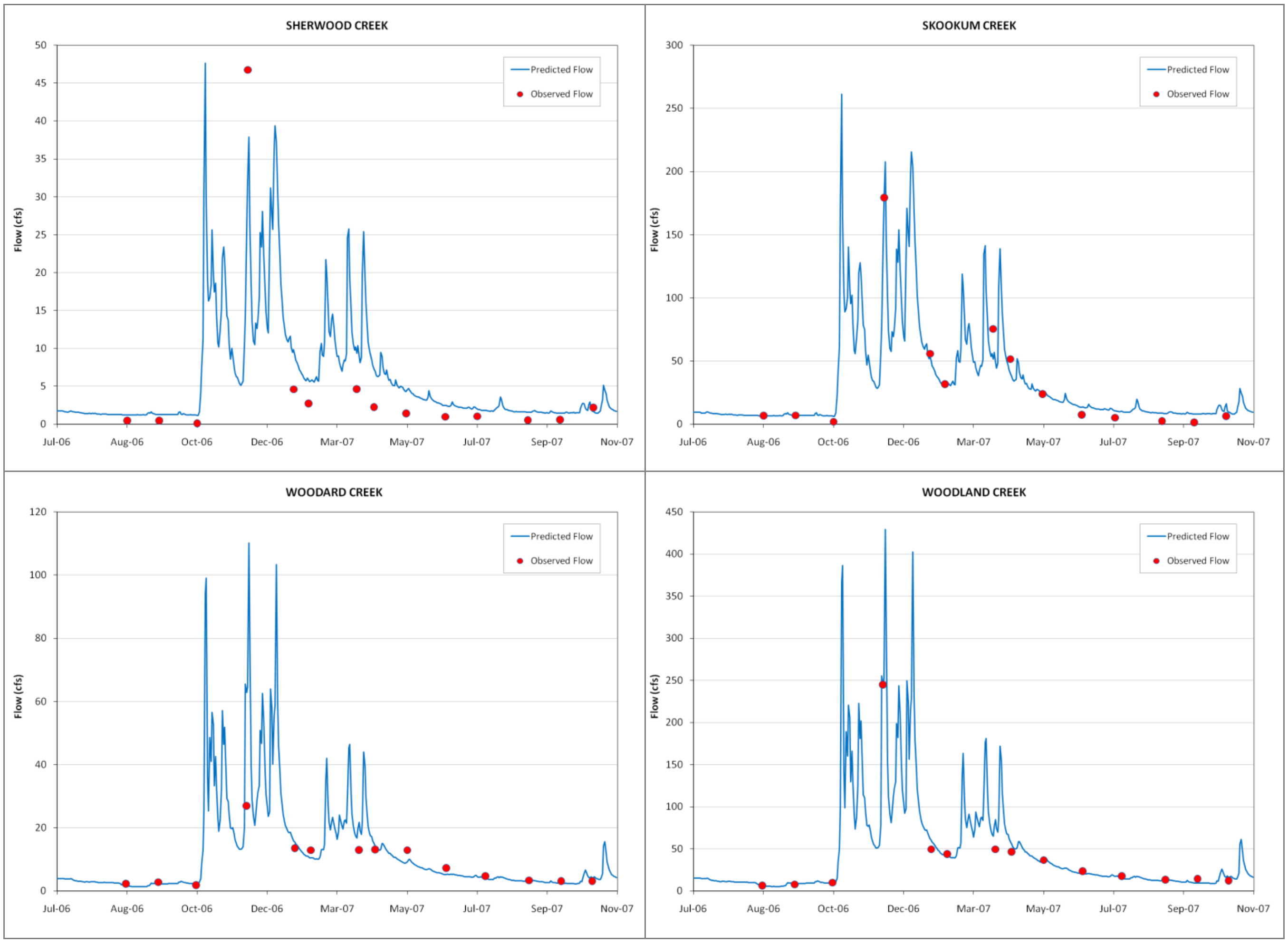

Figure B-2. Predicted and observed flows on creeks where 15 months of data were collected between July 2006 and October 2007.

Figures B-3 through B-5 compare predicted and observed flows at creeks which did not have USGS gages located within their watersheds, but where instantaneous flow measurements were taken monthly for four months.

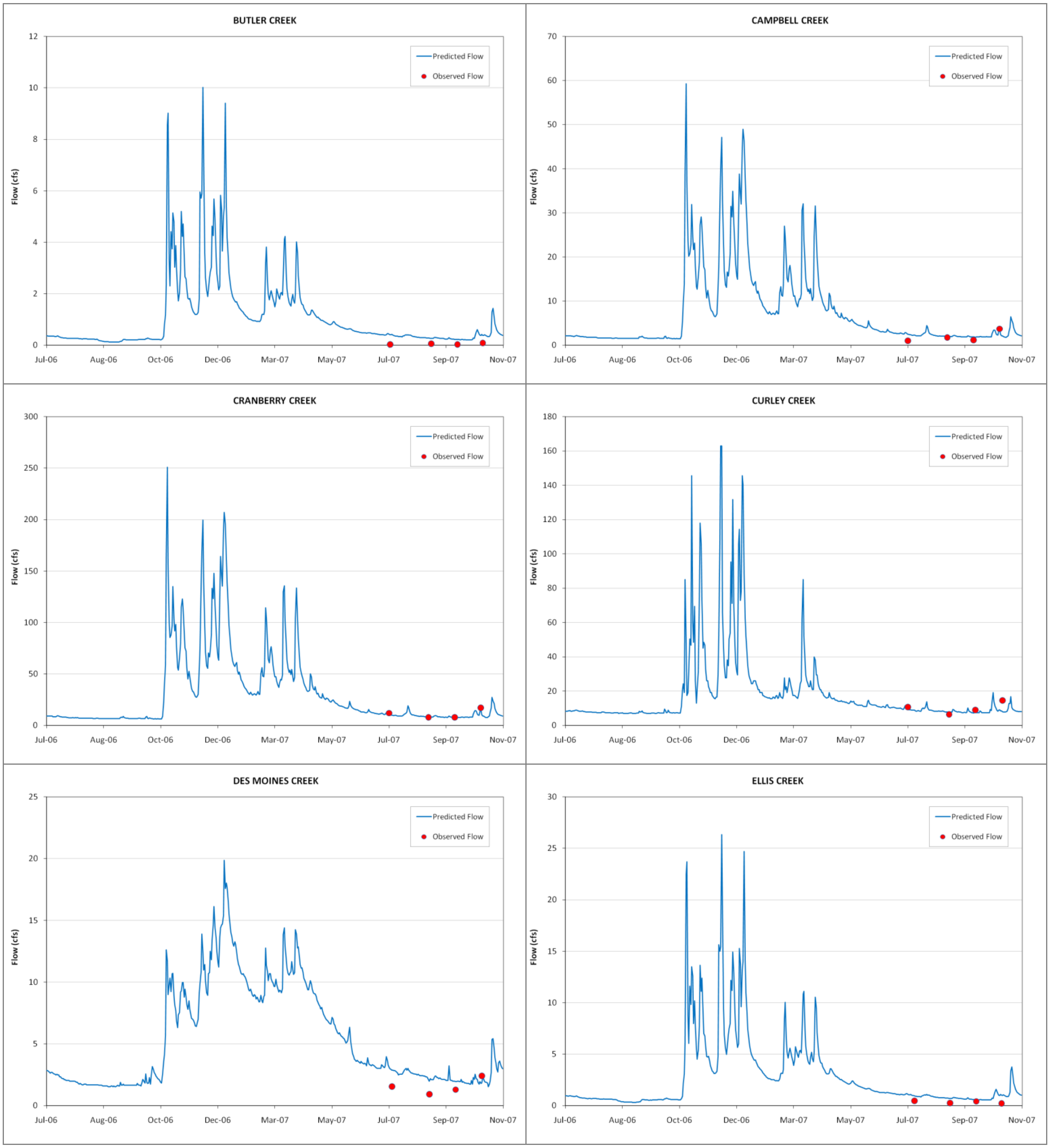

Figure B-3. Predicted and observed flows on creeks where 4 months of data were collected between July 2006 and October 2007.

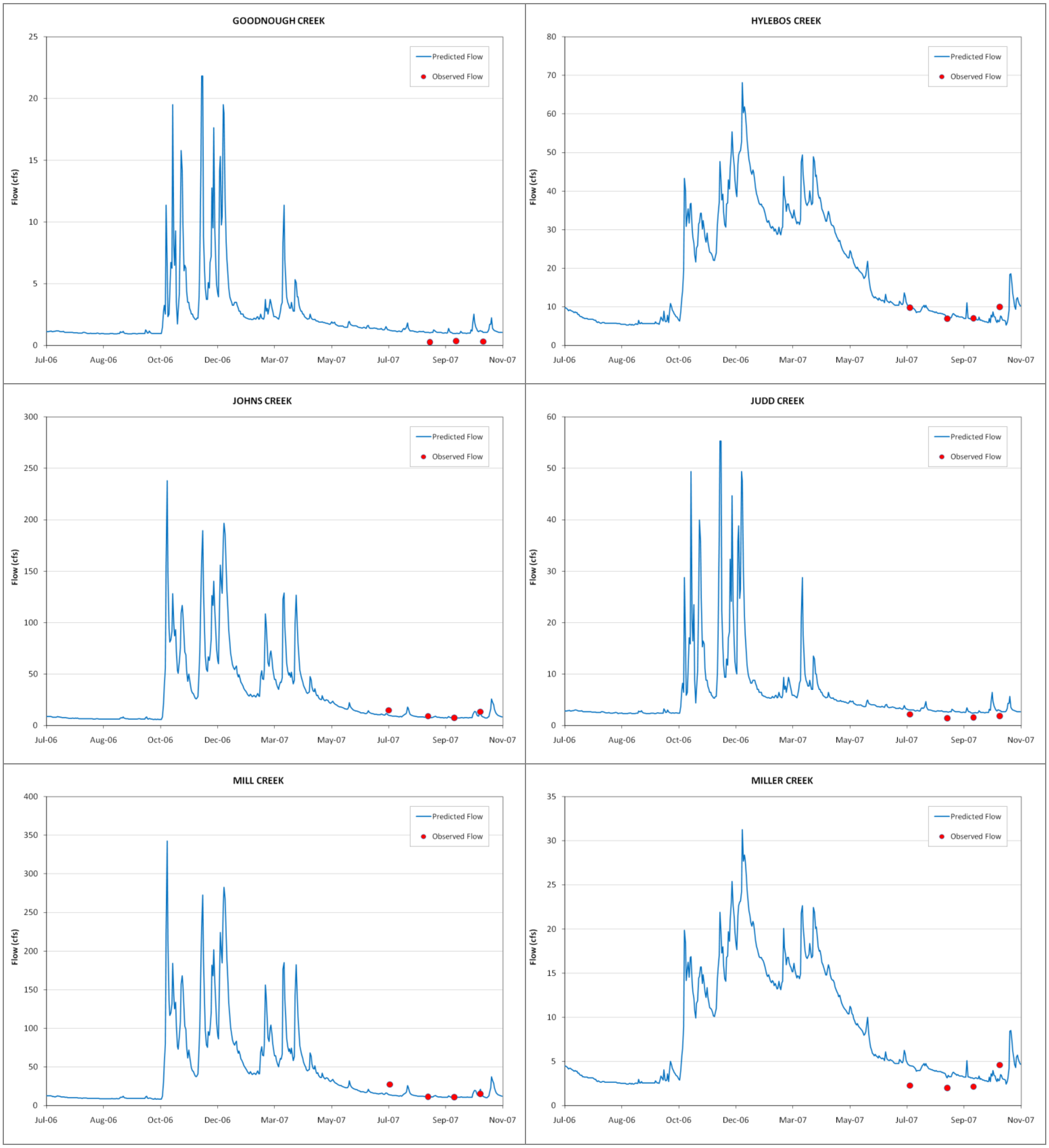

Figure B-4. Predicted and observed flows on creeks where 4 months of data were collected between July 2006 and October 2007.

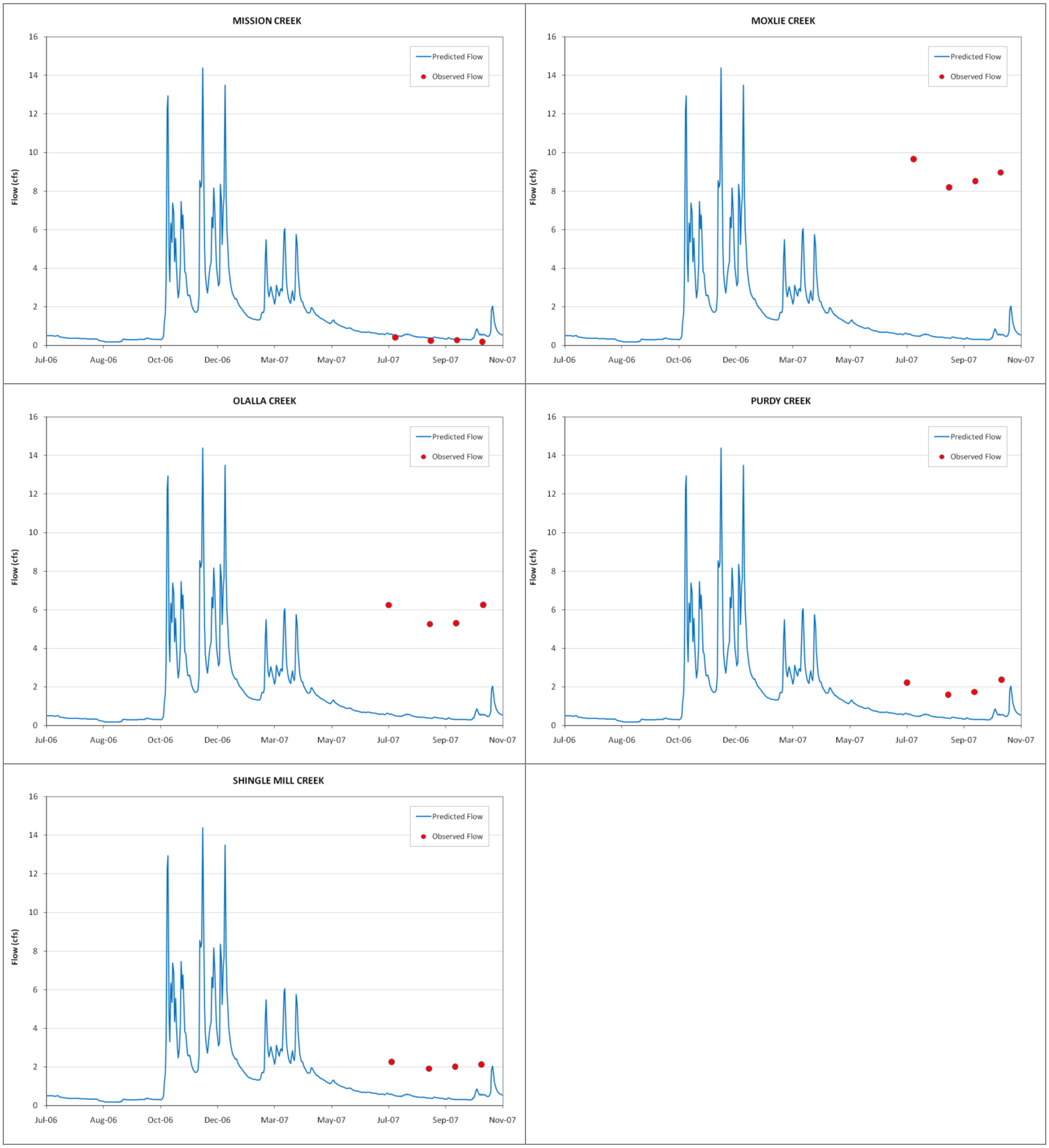

Figure B-5. Predicted and observed flows on creeks where 4 months of data were collected between July 2006 and October 2007.

Appendix C. Analysis of On-Site Septic System Loads

Disclaimer: This appendix is a separate report which has an "Appendix A" within it. The main report also has an Appendix A (Glossary, Acronyms and Abbreviations). The two "Appendix A" are therefore not the same.

T E C H N I C A L   M E M O R A N D U M

November 29, 2010

Anthony J. Whiley, P. E.

Washington State Department of Ecology

Estimate of dissolved inorganic nitrogen (DIN) loading associated with on-site wastewater systems situated outside of monitored catchments and municipal wastewater service areas within the south Puget Sound study area.

Analysis Purpose

This analysis was initiated to provide an estimate of the annual average dissolved inorganic nitrogen (DIN) entering the south Puget Sound study area associated with on-site wastewater system discharge. It serves as a supplement to the on-going South Puget Sound Dissolved Oxygen Study which is examining DIN loading, its movement within the south Puget Sound, and its organic and inorganic effects to water quality. That effort monitored DIN levels within 39 catchments which together comprised 8,737 km^2 or about 75% of the 11,711 square kilometer (km^2) study area. The surface area of marine waters comprises approximately 8% of the study area therefore the monitored catchments comprise about 81% of the land-based drainage. The south Puget Sound study applied the catchment monitoring data to calculate annual DIN loads. In addition, annual DIN loads were determined for 29 point source discharges (primarily municipal wastewater treatments systems). However, missing was an assessment of the DIN load from sources lying outside those served by the municipal wastewater treatment systems and the monitored catchments. For this reason, this analysis examined these "unknown" areas, which will be referred to in this memorandum as the exclusive area, with a focus on providing an estimate of the annual DIN load associated with on-site wastewater systems. (The greater study area, monitored catchments, municipal wastewater service areas along with the exclusive area are presented in Figure A1 (refer to Appendix A.)

Methods

To estimate the DIN load associated with on-site wastewater systems in the exclusive area the following variables were considered:

- Number of residences (and associated population) utilizing on-site wastewater systems.
- Wastewater flow rates.
- DIN wastewater concentrations.
- DIN attenuation levels in environment.

Application of Geographic Information Systems

The majority of this analysis was conducted through application of the geographic information systems software Arc View (ver. 9.3). The following data layers (covers) were assembled to initiate the project:

- Land parcels with current (2008) county assessors designations of residential housing type and other land use designations.

- Delineation of municipal wastewater service areas discharging to Puget Sound within study area.
- Delineation of monitored catchments.
- Delineation of Puget Sound shoreline.
- Census (2000) tracts, which includes data on population and housing levels.
- Delineation of study area.
- Water resource inventory areas within study area.
- Surface water drainage network (1:24,000).

Central to this analysis was the use of a polygon cover of tax parcels that included Washington State Department of Revenue land use designations. Among the land use designations, or codes, ascribed to each parcel were several describing various types of residential housing. This analysis focused on parcels identified by the following designations: single family units, residential 2-4 units, multi-residential (x>5 units), residential condominium, mobile home park, hotel/motel, institutional lodging, other residential, and vacation/cabin.

To both streamline and refine the analysis the land parcel polygons were converted to centroids (point cover indicating the center of each parcel polygon) through the x-tools extension within Arc View. Following the conversion, the parcel centroids (covering the state) were clipped to the greater study area boundary. This then provided an assessment of all parcels located within the study area.

The parcels of interest were, however, those exclusive of the monitored catchments and municipal wastewater service areas. Therefore, centroids situated within either of these types of delineations, throughout the study area, were selected and removed. Left were all parcels located in the exclusive area residential and otherwise. It was assumed that all parcels with a residential-type designation utilized an on-site wastewater treatment system. The monitored catchments, municipal wastewater service areas and parcel centroids (defining the exclusive area) are presented in Figure A1 (refer to Appendix A).

Application of Parcel and Census Tract Data

The primary reason for utilizing the tax parcel information was to identify all residential-type land use and, therefore, locations of on-site wastewater systems within the exclusive area. An accounting of the various types of housing also provided a means of estimating population, a critical variable in estimating the DIN load associated with on-site systems. In order to complete that type of assessment the relationship between the number of housing units identified by Census tract was compared with that determined by the tax parcel data.

Twelve Census tracts situated entirely within the study area were selected at random. An accounting of all parcels situated within each of the Census tracts was determined. (For this part of the analysis the entire set of parcel centroids (within the study area) was considered.) From the parcel information, the various residential-types were enumerated and compared to those reported through the Census. A weighting factor was used to relate the various types of residential housing to a single family unit equivalent. For instance, single family residences were given a weighting factor of 1while vacation/cabin residences were given a weighting factor of 0.25, reflecting that a cabin is occupied only a portion of the year (estimated at around 3-months). The ultimate weighting factors applied were as follows: single family units (1), residential 2-4 units (3), multi-residential (x>5 units) (5), residential condominium (2), mobile home park (5), hotel/motel (100), institutional lodging (100), other residential (0.25), and vacation/cabin (0.25). While many of the weighting factors used follow from the designation (i.e. 3 for a 2-4 residential unit), the weighting factors for condominium, mobile home park, hotel/motel and institutional lodging were determined based on providing the best fit linear relationship between the two sets of data (r^2=0.82, refer to Figure A3 in Appendix A). Relating the 2008 parcel information to 2000 Census data provides a conservative estimate of housing due to the expected increased development occurring during this period. However, much of the exclusive area is relatively rural with a reduced level of development pressure. Higher levels of development would be expected to occur in proximity to municipal wastewater service, areas that were excluded from consideration by this analysis.

To determine the average number of occupants per residence all census tracts located within the study area were selected and the occupants per residence calculated per tract. An overall average level of 2.5 occupants per residence was determined with a standard deviation of 0.6.

This 2.51 level of occupancy was applied to the number of equivalent residences determined from the tax parcel data to estimate the population. This population estimate, determined for each of the 12 census tracts based on the number of housing equivalents, was then compared to the population reported by the 2000 Census. The method provided a reasonable fit with a coefficient of variation of 0.91 (refer to Figure A4 in Appendix A).

The reason for these gyrations is that the application of the tax parcel information yields more information, providing a more rigorous spatial analysis approach (provides location of on-site systems), in relation to solely applying the Census tract data. Also, Census tracts (or blocks) extend, in many cases, beyond the study area boundary requiring an area weighting method which may not be appropriate as it assumes an equivalent residence and population distribution throughout the tract. Ultimately, all tax parcels situated beyond the monitored catchments and municipal wastewater service areas (exclusive area) were grouped by water resource inventory area (WRIA) and then sorted by land use (residential-type designation). For each WRIA, an enumeration of the various housing types was conducted and a residential housing equivalent determined. Based on the residential housing equivalent, the associated population was determined by applying the 2.5 capita per residence factor determined from the 2000 Census information.

Estimate of Residential Water Use

The relationship between average July/August municipal wastewater treatment flow levels observed at municipal wastewater treatment plants and the residential population served by the plant was used to estimate typical residential wastewater flow levels. Eight wastewater treatment plants situated within the study area were evaluated. The July/August period was chosen because it represents a time when precipitation is at an annual low minimizing the influence of inflow and infiltration. It is assumed that for the plants examined the primary inflow source is residential-based with minor industrial inflow. The service area delineation was used to identify all residential parcels presumed connected to the treatment plant system. The enumeration of residential parcels allowed an estimate of the population served by each plant. Based on this assessment, the median per capita wastewater flow is 93 gallons per day (Table 1). This estimate is on the higher range of reported per capita residential wastewater flows which tend to have a range between 40 and 80 gallons per day (Metcalf and Eddy, 1991). An analysis of daily in-door residential water use in the United States was found to average 69 gallons per day with a standard deviation of 40 (EPA, 2002). Given the wastewater flow approach appears to estimate toward the higher end of typically reported values, this analysis will assume the reported 69 gallons per capita per day average indoor water use.

Table 1. Several greater study area municipal wastewater treatment plants, their average July/August flow levels, estimated population served, and estimated per capita wastewater flows.

Plant Name	Permit No.	Avg. July/August Flow (million gallons per day)	Residences/Population	Wastewater Flows (gallons/capita-day)
Vashon	22527	0.078	282 / 620	126
Duvall	29513	0.390	1,946 / 4,281	91
Port Orchard	20346	1.371	6,518 / 14,340	96
Central Kitsap	30520	3.210	15,763 / 34,679	93
Puyallup	37168	3.050	15,000 / 33,000	92
Bremerton	29289	3.830	17,747 / 39043	98
Redondo/Lakota (grouped)	23451	6.329	32,559 / 71,630	88
LOTT (Olympia)	37061	8.800	44,611 / 98144	90

On-Site Effluent DIN

Typical total nitrogen (TN) wastewater loading rates, on a per capita basis, is about 4.8 kg N/capita – year (Bowen, 2001). Based on an average daily per capita in-door domestic water use of 69 gallons per day (262 liters per day), this works out to an average influent TN concentration of 50 mg/L. Literature values for the TN concentration of raw domestic wastewater (influent) tend to range between 35 to 80 mg/L with the on-site system effluent concentrations between 25 to 60 mg/L (Metcalf and Eddy, 1991). A survey of on-site system effluent found an average TN concentration of 45 mg N/L with a standard deviation of 18 mg/L (University of Wisconsin, 1978 in Cantor and Knox, 1988). That study determined that about 30% of the nitrogen is in an organic form with the primary nitrogen form ammonia-N which averaged 31 mg/L (standard deviation=14 mg/L). Typical values for total Kjeldahl nitrogen (TKN =organic-N + DIN) is 70.4 mg/L, with ammonia–N comprising 41.2 mg/L of that total with the remainder, or 29.1 mg/L, (41% of TKN) organic-N (Crites, 1998). Once introduced to the soil matrix effluent ammonia-N is oxidized to nitrate which then typically becomes the dominant inorganic form of nitrogen within surface and groundwater. Based on an average TN effluent concentration of approximately 50 mg/L and assuming that 35% is in an organic form, then the ammonia-N concentration is around 33 mg/L. This sets the ammonia-N concentration at a level close to that reported based on a more extensive analysis of on-site effluent (μ=31 mg/L, α=14 mg/L) (Canter and Knox, 1988). For this reason, this analysis will apply the 31 mg/L ammonia-N level for estimating on-site DIN loading.

Estimate of DIN loss

Following discharge to sub-surface soil layers, there are a number of potential pathways that wastewater-related DIN can take including de-nitrification, or the loss of nitrogen to its elemental gas form (N_2), and that lost through incorporation into organic (plant) growth. DIN loss occurring through the latter pathway can be substantial if the groundwater flow path is bisected by dense riparian growth prior to surface water discharge. Though site specific, de-nitrification tends to occur as nitrate migrates through the interface between the soil matrix and the water table where anaerobic conditions are present. This process may also be repeated as nitrate, present in the groundwater, is discharged to surface water further afield. The number of environmental variables determining the level of de-nitrification is large and though relatively well studied continues to be poorly defined. This is because environmental characteristics such as soil (organic and mineral composition), underlying geology (depth to bedrock), and water table flow pathways are all highly variable. Based on a review of reported de-nitrification rates (first order) the median level was found to be 0.025/day (approximately 2.5%/day) with a range of 0.004-2.27/day (McCray, 2005). An analysis of de-nitrification rates associated with on-site effluent in Mason County (Hood Canal) determined a median level of 0.06 mg/L-day (zero order) (Horowitz, 2008). The USGS applied a de-nitrification loss rate of 10% to its assessment of DIN loading associated with shoreline-based on-site systems in Hood Canal (Paulson, 2006). Analyses of nitrate attenuation conducted further afield of on-site drain fields reported levels as high as 90% (Horowitz, 2008).

This study examined end-of-pathway DIN loading within 19 primarily residentially developed catchments within the study area that solely utilize on-site wastewater treatment. These catchments tend to be suburban to rural with lower development levels. The range in the number of residences per hectare was 0.01 to 1.1, with a median level of 0.2 (residences/hectare). The median catchment area was 2901 hectares with a range of 124 to 8,576 hectares. The catchments tended to have well established riparian corridors.

For each catchment, average flow and nitrate concentrations were determined based on measurements collected during July and August. From this information, a low-flow nitrate load was determined. The reason for examining the low flow condition is that it is a period when groundwater discharge is the primary source of flow and the nitrate concentrations associated with it more accurately characterize the long-term nitrogen loading to groundwater within the catchment. During the winter months, more flow within the stream is derived from overland flow bringing with it nitrate from a greater variety of sources (i.e. fertilizer, animal wastes etc.). It is assumed that within these residentially developed catchments, nitrate from on-site systems is the primary source to groundwater because it is directly delivered to the sub-surface soil matrix whereas the pathway of surface-based nitrate sources (animal waste, fertilizer) within the environment is primarily overland flow with lower penetration to groundwater. It is recognized that there are naturally occurring background sources in these catchments though it is assumed that their contributions to stream concentrations are insignificant. (Median July-August DIN levels in the relatively un-impacted upper Mashel River catchment (a tributary to the Nisqually River) was observed at 43 ug/L (Whiley, 1994) , 86% lower than the median level (300 ug/L) observed in the assessment streams.)

Once determined, the catchment nitrate loads were compared to those calculated based on the number of residences present within each catchment and assumed wastewater characteristics. In calculating the on-site loads it was assumed that the average per capita water usage was 69 gallons per day (gpd), the DIN concentration within the associated wastewater was 31 milligrams per liter (mg/L) (Canter and Knox, 1988), and the average capita per residence was 2.51. Based on these characteristics, the annual DIN load delivered to the soil matrix is around 2.96 kilograms per capita.

Overall, among the catchments, the median residential-based DIN load was estimated at 8.51 kg/d (refer to Table A2 in Appendix A). In comparison, the median catchment base-flow DIN load was 2.32 kg/d, indicating an overall loss of about 70%. As expected, these attenuation rates are highly variable with the inner quartile range between 43-88%. (Assuming a background DIN concentration of 0.04 mg/L, the median attenuation level increases slightly to 73%.)

These results indicate that DIN loss can be substantial if the on-site effluent travels a complex flow path encountering organic/anaerobic interfaces, allowing for more extended de-nitrification. Incorporation into organic growth (plant-animal) as groundwater up-wells and discharges through the riparian corridor is another route of attenuation. Unfortunately, much of the residential development within the exclusive area is situated along the marine shoreline characterized by relatively short flow transit prior to surface water discharge, providing a reduced opportunity for de-nitrification.

Results

Housing and Population within the Exclusive Area

Among the residential land use types identified in the exclusive area, single family residences are the most highly represented at 88% of the total, followed by 2-4 units (3.5%), condominiums (2.4%) and other residential (2.1%). The remainder of the residential types are represented at approximately 1% each (Table 2).

The exclusive area includes the following water resource inventory areas: Chambers-Clover, Deschutes, Duwammish-Green, Kennedy-Goldsborough, Kitsap, Nisqually, and Puyallup-White (refer to Figure A1). (Though present within the study area, the Cedar-Sammamish WRIA was not represented in this assessment due to catchment monitoring and extensive municipal wastewater service coverage.) Among the 80,702 residences occurring within the exclusive area, 69% or 55,863 occur in the Kitsap WRIA. The next highest WRIA represented is the Deschutes with 10% (8,065 residences) followed by Kennedy-Goldsborough at 8% (6,283 residences) and Puyallup-White at 8% (6,184 residences). The total population within the exclusive area was estimated at 202,562.

Table 2. Total accounting of residential-type housing occurring within the exclusive area, by WRIA; along with the assessment of housing equivalents and their associated populations.

Housing Description	Water Resource Inventory Area							
	Chambers-Clover	Deschutes	Duwammish-Green	Kennedy-Goldsborough	Kitsap	Nisqually	Puyallup-White	Total
Single Family	130	6,910	2,769	4,067	51,243	668	4,888	70,675
2-4 Units	5	151	31	26	517	29	186	945
>5 Units		12	13	3	140	6	29	203
Condominium		98	3		418	282	156	957
Mobile Home		66		9	34	9	31	149
Hotel/Motel				1	9			10
Inst. Lodging				5				5
Other Residential	5	463		4,489	1,701	131	106	6,895
Cabin/Vacation				1,029	151			1,180
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Residential Equivalents	146	8,065	2,933	6,184	55,863	1,427	6,084	80,702
Associated Population	367	20,243	7,362	15,522	140,216	3,582	15,271	202,562

Of this larger data set, residences were grouped by both WRIA and proximity to shoreline: residences within 150-meters of the shoreline and those beyond 150-meters of the shoreline. The 150-meter distance was selected because it marked an inflection point in the density of housing in proximity to the shoreline (refer to Figure A6 in Appendix A). This separation is used later in determining the annual DIN loading rate because it identifies residences situated closest to the shoreline that have the least possibility of DIN attenuation. (Figure A2 provides a detail of this analysis approach.)

Of the total residences situated within the exclusive area, approximately 20% are within 150-meters of the shoreline (Table 3; Figure A7). Among the WRIAs, 22% (14,274) of the Kitsap residences are situated within 150-meters of the marine shoreline. The Kennedy-Goldsborough WRIA also shares a similar representation of shoreline-based residential development (1,565) in relation to its total number of residences.

Table 3. Enumeration of marine shoreline-based residential-type housing (within 150-meters of shoreline) included within the exclusive area, by WRIA; along with the assessment of housing equivalents and their associated populations. (This is a subset of the total housing and population data presented in Table 2.)

Housing Description	Water Resource Inventory Area							
	Chambers-Clover	Deschutes	Duwammish-Green	Kennedy-Goldsborough	Kitsap	Nisqually	Puyallup-White	Total
Single Family	115	1,469	178	906	11,062	19	85	13,834
2-4 Units	4	6		2	75			87
>5 Units		1	1	2	68			72
Condominium		13			98			111
Mobile Home		1		3				4
Hotel/Motel					3			3
Inst. Lodging								
Other Residential	4	69		2,033	642	2		2,750
Cabin/Vacation				478	78			556
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Residential Equivalents	128	1,540	183	1,565	12,303	20	85	15,824
Associated Population	321	3,866	459	3,928	30,881	49	213	39,717

Estimate of DIN load from Exclusive Area

Assumptions used to calculate the DIN load for the exclusive area include:

- DIN load associated with residences within 150-meters of the marine shoreline has a loss rate of 10% due to de-nitrification (Paulson, 2006).
- DIN load associated with residences beyond 150-meters of the marine shoreline has an overall loss rate of 70% due to de-nitrification and organic growth.
- Residential occupancy rate of 2.51 people.
- Wastewater discharge rate of 69 gallons per person per day.
- An on-site effluent DIN concentration of 31 mg/L.
- On-site system DIN loading to shallow groundwater has remained relatively steady, occurring over a sufficient period to have reached steady state. Therefore, the DIN load associated with

on-site effluent discharged to surface soils annually within the exclusive area has reached equilibrium in relation to that assumed entering Puget Sound.

The base loading equation along with a summary of the underlying assumptions is provided in Tables 4 and 5, respectively.

Table 4. DIN load equation applied.

$$\boldsymbol{DIN\ Load}\left(\frac{\boldsymbol{tonnes}}{\boldsymbol{WRIA - year}}\right) =$$

$$Number\ residences\ \left(\frac{No.\ Residence}{WRIA}\right) * Capita\ per\ residence\ \left(\frac{capita}{residence}\right) * Wastewater\ generation\left(\frac{gallons}{capita - day}\right) * DIN\ effluent\ concentration\left(\frac{mg}{liter}\right) * Attenuation\ Factor$$

$$\text{Unit Conversion: gallons to liters } \left(\frac{0.00379\ m\text{^}3}{gallon}\right) * \left(\frac{1000l}{m\text{^}3}\right);\ \text{mg to tonne } \left(\frac{g}{1000mg}\right) * \left(\frac{kg}{1000g}\right) * \left(\frac{tonne}{1000kg}\right);\ days\ to\ year\left(\frac{365d}{year}\right)$$

Table 5. Load calculation assumptions based on proximity to shoreline.

Loading Assumption Applied	Proximity of Onsite System to Shoreline	
	<=150m	>150m
DIN Effluent Concentration (to drainfield)	31 milligrams per liter	
Capita per Residence	2.51 capita per residence	
Attenuation Factor (loss)	10%	70%
Wastewater generation	69 gallons per capita	

Based on these assumptions, the annual DIN inflow to the Puget Sound from on-site systems located in the exclusive area is 250 tonnes or 1.24 kg DIN/capita-yr (Table 6). Of that total, 106 tonnes or 42% of the annual area-wide loading total is derived from systems located within 150-meters of the marine shoreline. The DIN loading yield for the shoreline based residences is estimated at 2.67 kg/capita-yr. A similar yield (2.95 kg/capita-yr) was found for shoreline-based DIN loading associated with onsite systems for Hood Canal (Paulson, 2006). In comparison, the estimated DIN loading associated with on-site systems further removed (greater than 150-meters from shoreline) was 145 tonnes, 58% of the area total. While the DIN loading associated with onsite systems beyond 150-meters of the shoreline was greater due to an approximately four times greater population, the assumed higher attenuation rate significantly reduced the estimated loading to Puget Sound. The DIN loading yield associated with onsite systems greater than 150-meters of the shoreline was estimated at 0.89 kg/capita-yr. The three-fold decrease reflecting the assumption that for onsite systems located within 150-meters of the shoreline that 90% of the loading eventually migrates to Puget Sound while on-site systems further removed, 30% is assumed migrating to Puget Sound.

Assuming no attenuation in DIN associated with onsite effluent results in a total annual load of 599 tonnes or 2.96 kg/capita-yr. Therefore, the net attenuation rate assumed for the area is 58%. (Table A1 presents these annual loads at a daily rate.)

Table 6. Estimated annual DIN loads to Puget Sound from on-site wastewater system located within the exclusive area (loads are in units of tonnes per year).

Base Assumptions		Water Resource Inventory Area							Annual Load Total (t/yr)
		Chambers-Clover	Deschutes	Duwammish-Green	Kennedy-Goldsborough	Kitsap	Nisqually	Puyallup-White	
With loss assumptions	x<150-m	0.86	10.30	1.22	10.46	82.24	0.13	0.57	105.78
	x>150-m	0.04	14.54	6.13	10.29	97.06	3.14	13.37	144.57
	Total=	0.90	24.84	7.35	20.75	179.3	3.27	13.94	250.35
Without loss assumptions	x<150-m	0.95	11.44	1.36	11.62	91.38	0.14	0.63	117.52
	x>150-m	0.14	48.46	20.42	34.31	323.52	10.45	44.56	481.86
	Total=	1.09	59.90	21.78	45.93	414.90	10.59	45.19	599.38

DIN loading considering attenuation and parameter variability

The previous DIN loading estimates were based on the application of median parameter values. However, there is considerable variability for many of these parameters which can have a significant effect on the loading estimates. In addition, while this analysis used both reported and determined estimates of net DIN attenuation, it is recognized that this parameter has high variability reflecting the varied physical and environmental factors encountered. To account for these various uncertainties, a Monte Carlo-type analysis approach was applied.

The analysis took the form of generating results for 1000-iterations of loading estimates, for varying DIN attenuation levels, through the application of the Excel formula: NORMINV(rand(), mean, standard deviation). The formula generates a random parameter value based on its sample mean and standard deviation. The underlying assumption in the use of this formula is that the parameter distribution is normal. The NORMINV() function was applied to the parameters: population per residence (μ=2.51, α=0.61; U.S Census), on-site effluent DIN concentration (μ=31 mg/L, α=14 mg/L; Canter and Knox, 1988), and wastewater generation per capita (μ=68 gal., α=40 gal.; EPA, 2002).

In addition to applying the NORMINV() function, to examine how loading varied based on different attenuation rates, a data table was applied. Within the data table, attenuation rates varied from 0% (no loss) to 100% (complete loss). These attenuation levels therefore are net levels, reflecting an overall average because the shoreline and upland based residences were not separated. For each attenuation level, percentiles were generated from the approximately 1000 associated loading estimates and a box plot graphic generated.

Regarding the interpretation of the box plot graphic: the upper and lower sides of the central box indicate the 75th and 25th percentiles of the data set; the dot and horizontal line within the box are the median (50th percentile) and average; while the upper and lower small squares (at end of upper and lower whisker extensions) are the 90th and 10th percentile of the DIN load estimates.

The utility of this type of analysis is that it provides an assessment of variability to the loading estimates. However, the difficulty in application is that the actual attenuation level attributed to on-site DIN loading is not known. This study assumed that the shoreline-based residences (those located within 150-meters of the shoreline) had a DIN attenuation level of 10% while those further removed from the shoreline (located beyond 150-meters) have an attenuation level of 70%. Referring to Figure 1, a worst case scenario (0% attenuation) has 75th, 50th, and 25th percentiles of 872, 496, and 219 tonnes per year in DIN loading, respectively. As observed, overall loading variability increases with reduced DIN environmental attenuation. (The average loads depicted in Figure 1 by the horizontal bar are those presented Table 6.) Previously, the net attenuation level, considering both that attributed to the shoreline and upland-based residences, was assumed to be 58%; close to the 60% level depicted in Figure 1. At the 60% attenuation level, the median loading estimate is 194 tonnes per year with the 75th and 25th percentiles 345 and 99 tonnes per year, respectively.

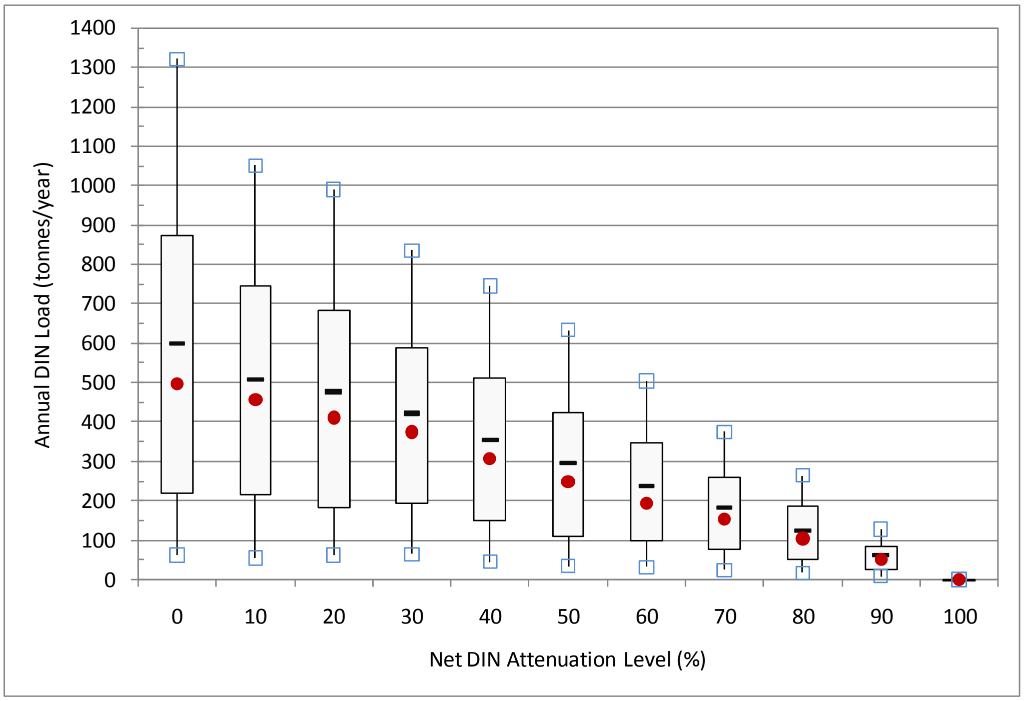

Figure 1. Box plots of predicted DIN loading for entire exclusive area provided varying attenuation levels.

Figure 2 presents box plots of the estimated annual DIN loads for the shoreline-based residences, those located more distant, and for the entire exclusive area. In review, the loading estimates are based on an assumed 10% attenuation level for the shoreline-based residences (those located within 150-meters of the shoreline) and 70% for those located more distant. A weighted average attenuation level for the entire exclusive area, based on the number of residences situated within each designation, was determined to be 58%.

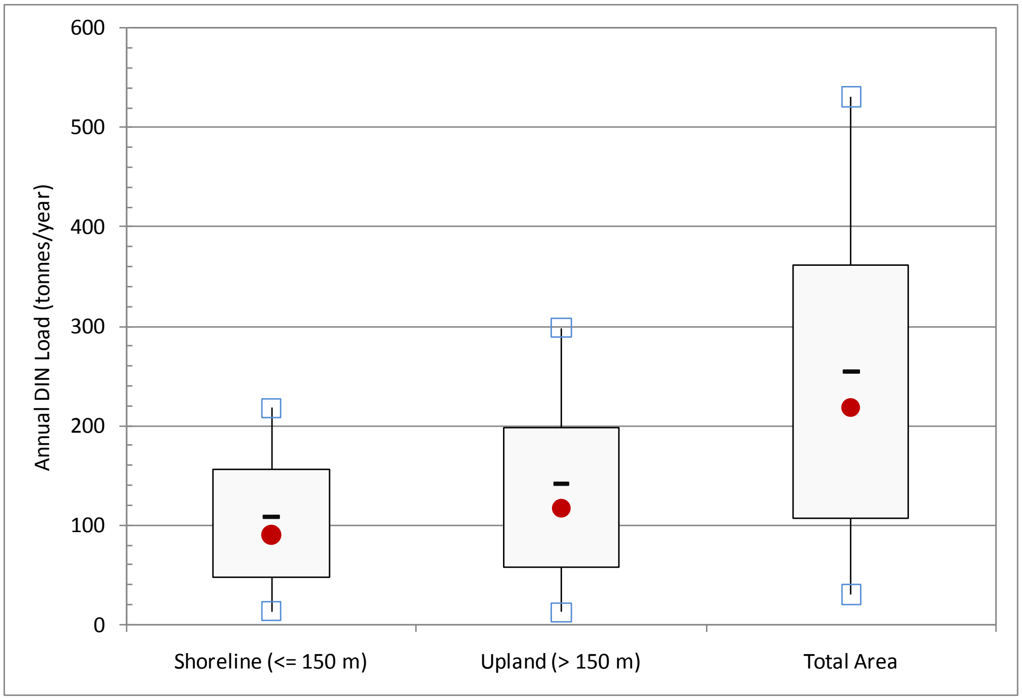

Figure 2. Box plots of the estimated annual DIN load (t/yr) associated with shoreline-based residences, those located upland, and their combined effect within the exclusive area.

Table 7. Annual DIN loading (t/yr) percentiles based on proximity to the marine shoreline and for the entire exclusive area.

Area Designation	Annual DIN Load (t/yr) Percentiles		
	25th	50th	75th
Total Area	107	218	362
Shoreline (<150 m)	48	90	157
Up-land (>150 m)	57	117	198

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Appendix A - Additional Figures and Tables

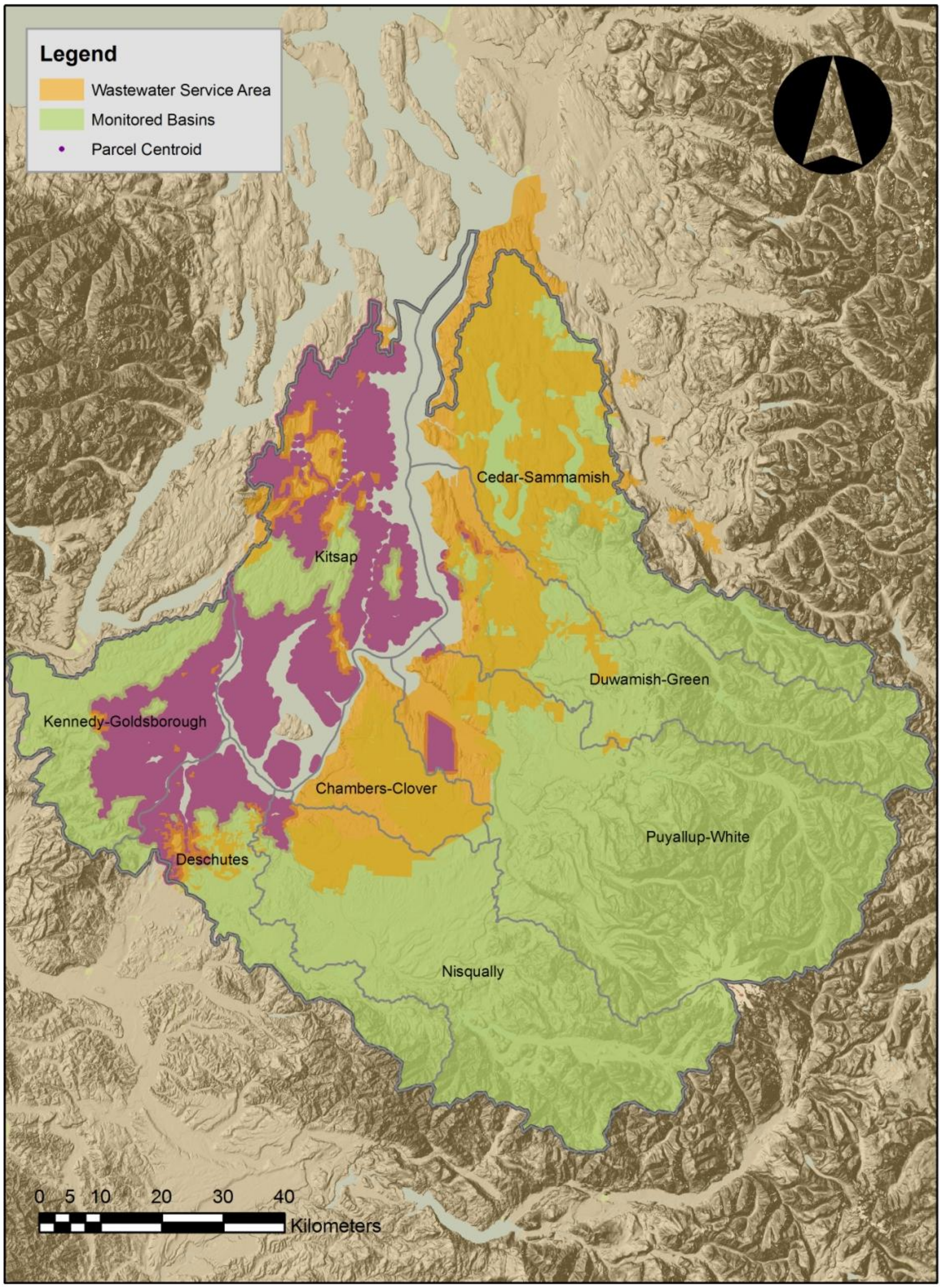


Figure A1. Study area defined by water resource inventory areas, monitored catchments (green), wastewater service areas (orange), and exclusive area (purple).

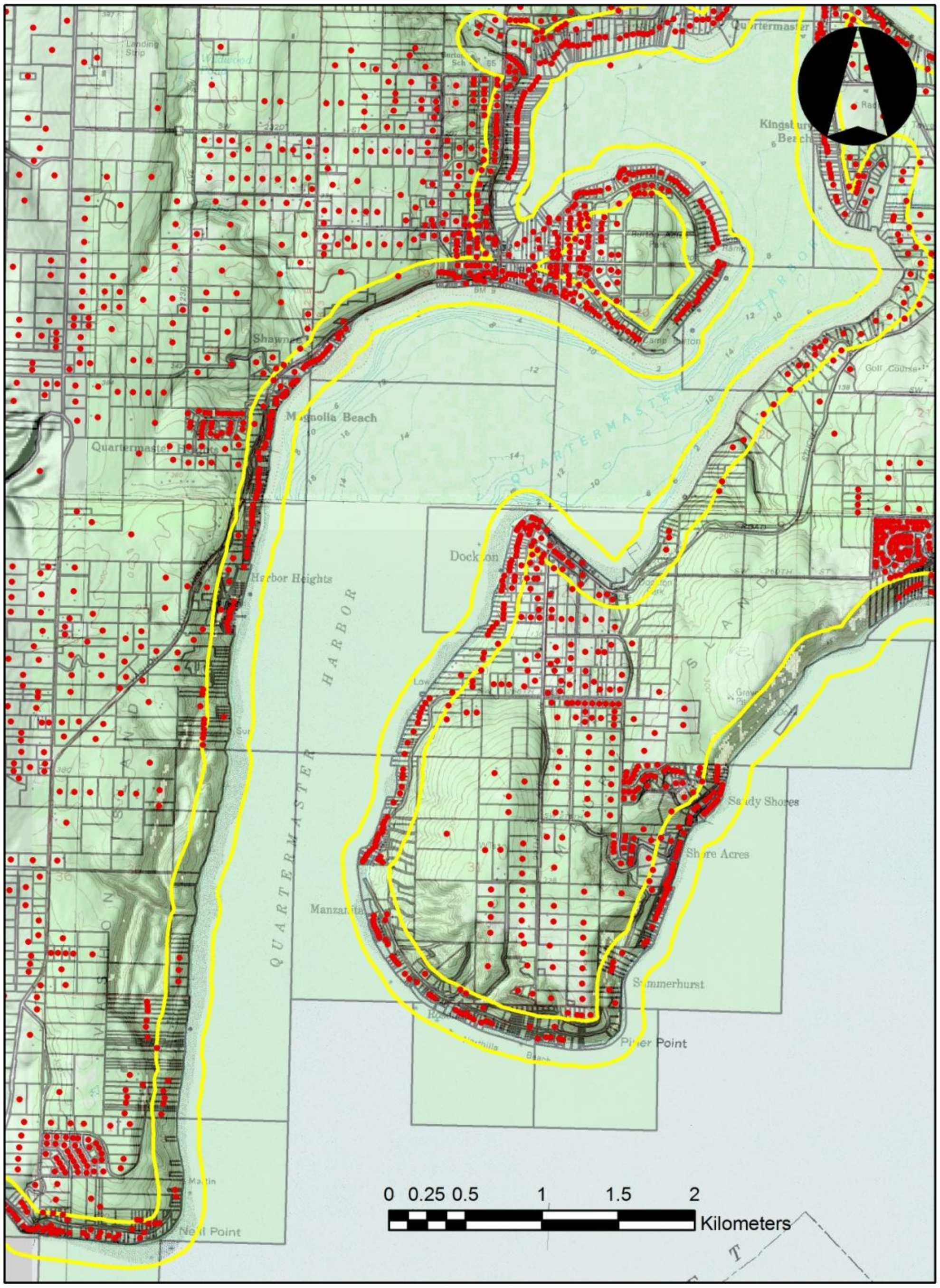


Figure A2. Study area detail (Quartermaster Harbor, Vashon Island) displaying parcels, parcel centroids identified as primary residential, and the 150-meter shoreline buffer.

Table A1. Estimated daily DIN loads to Puget Sound from on-site wastewater systems located within the exclusive area (loads are in units of kilograms per day).

Base Assumptions		Water Resource Inventory Area							Daily Load Total (kg/d)
		Chambers-Clover	Deschutes	Duwammish-Green	Kennedy-Goldsborough	Kitsap	Nisqually	Puyallup-White	
w/loss assumptions	x<150-m	2.36	28.22	3.34	28.66	225.32	0.36	1.56	289.82
	x>150-m	0.11	39.84	16.79	28.19	265.92	8.60	36.63	396.08
	Total=	2.47	68.06	20.13	56.85	491.24	8.96	38.19	685.90
w/o loss assumptions	x<150-m	2.60	31.34	3.73	31.84	250.36	0.38	1.73	321.97
	x>150-m	0.38	132.77	59.95	94.00	886.36	28.63	122.08	1320.16
	Total=	2.99	164.11	59.67	125.84	1136.71	29.01	123.81	1642.14

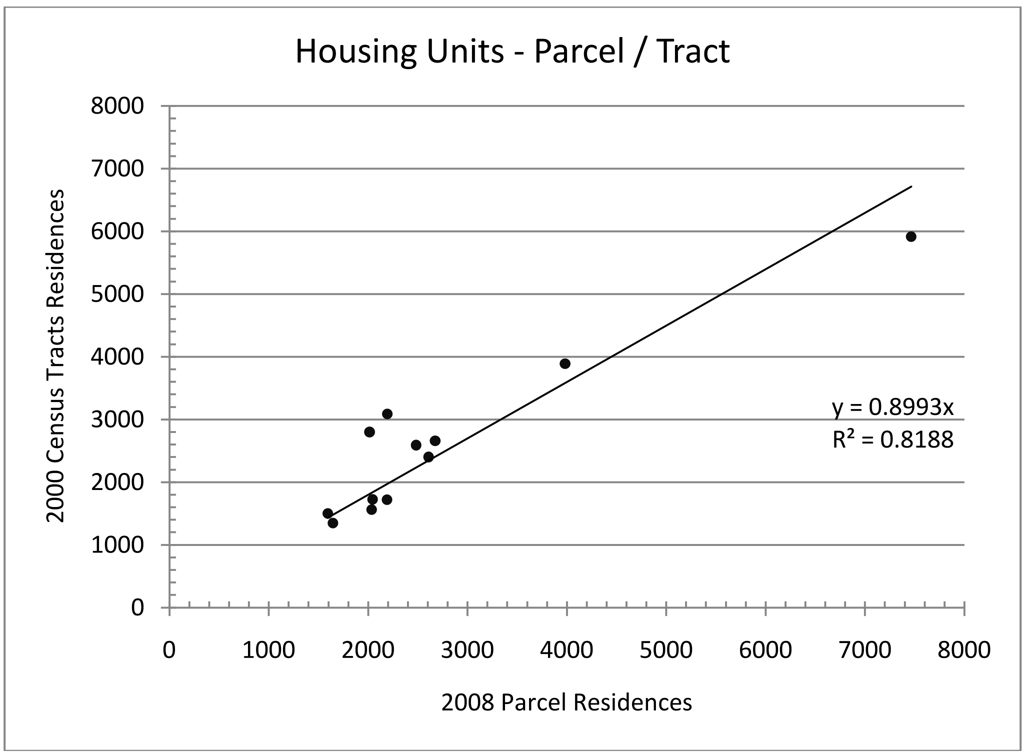


Figure A3. The number of residences estimated by the U.S. Census in relation to those estimated by county assessor parcel data based on several Census tracts within the study area.

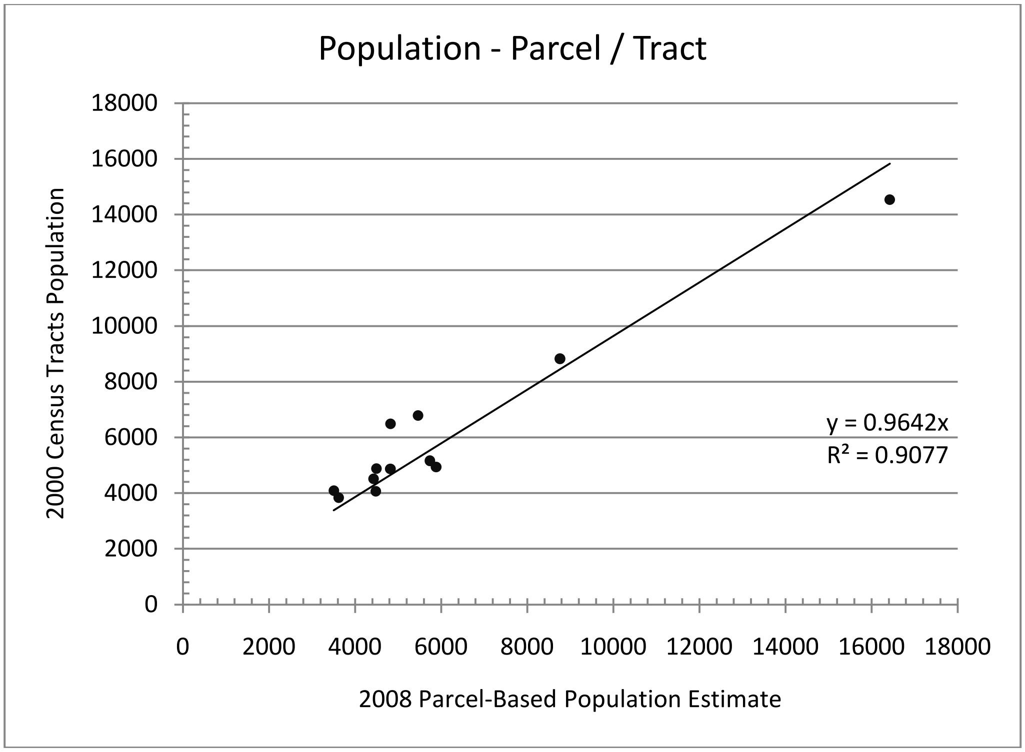


Figure A4. The population estimated by the U.S. Census in relation to estimates by application of county assessor parcel data, based on several Census tracts within the study area.

Figure A5 presents the relationship between the number of residences per hectare and median July/August nitrate concentrations observed in the monitored catchments. The majority of the monitored catchments are rural where maximum residential densities are typically set at 0.5 residences per hectare. From Figure A5, based on this residential density level, a median low-flow nitrate concentration of 0.610 mg/L is predicted. From the relationship, and assuming no residential development (y-intercept), a rough assessment of a "background" nitrate concentration can be determined for these catchments. The y-intercept based is 0.116 mg/L (116 ug/L). While in comparison, the July/August median nitrate concentrations of relatively un-impacted rivers (minimal residential and agricultural influences present) monitored as part of Washington State Department of Ecology's ambient monitoring such as the North Fork Stillaguamish River at Darrington (73 ug/L) and Green River at Kanaskat (62 ug/L). To be sure, there are other influences on groundwater nitrate concentrations in the monitored catchments other than on-site systems but this relationship suggests that their influence is a significant one.

Referring to Table A2 (below) within the monitored catchments the median residential density is 0.21 residences per hectare. From the relationship in Figure A5, this results in a stream concentration of 0.323 mg/L. If a background concentration of 0.116 mg/L is assumed, then the net residential contribution to stream nitrate concentration is 0.207 mg/L. Applying the median flow (0.11 m^3/s), this concentration results in a July/August nitrate load of 1.97 kg/d. In comparison, the median on-site nitrate load is estimated at 8.51 kg/d. This would indicate that the retention level is around 77%. To be sure, there is high variability in each component of this estimate, but it indicates overall that high nitrate retention is possible provided a complex flow path that encounters aerobic/anaerobic transitions, conducive to de-nitrification, along with biological uptake opportunities.

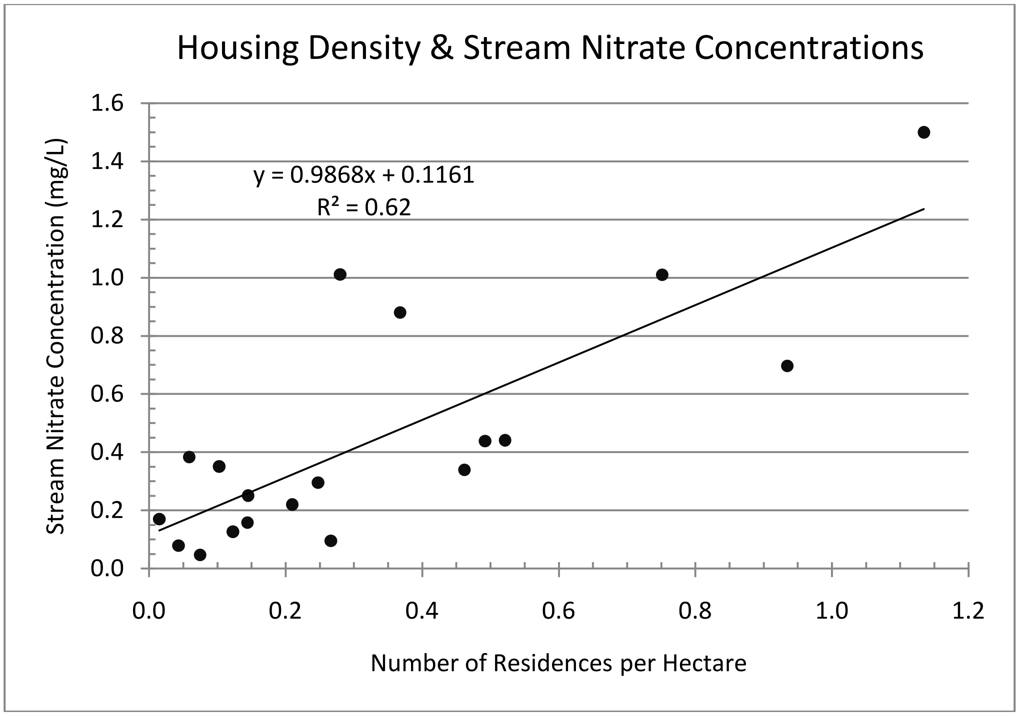


Figure A5. The relation between housing density (no./ha) and the median July/August nitrate concentration for several catchments within the study area.

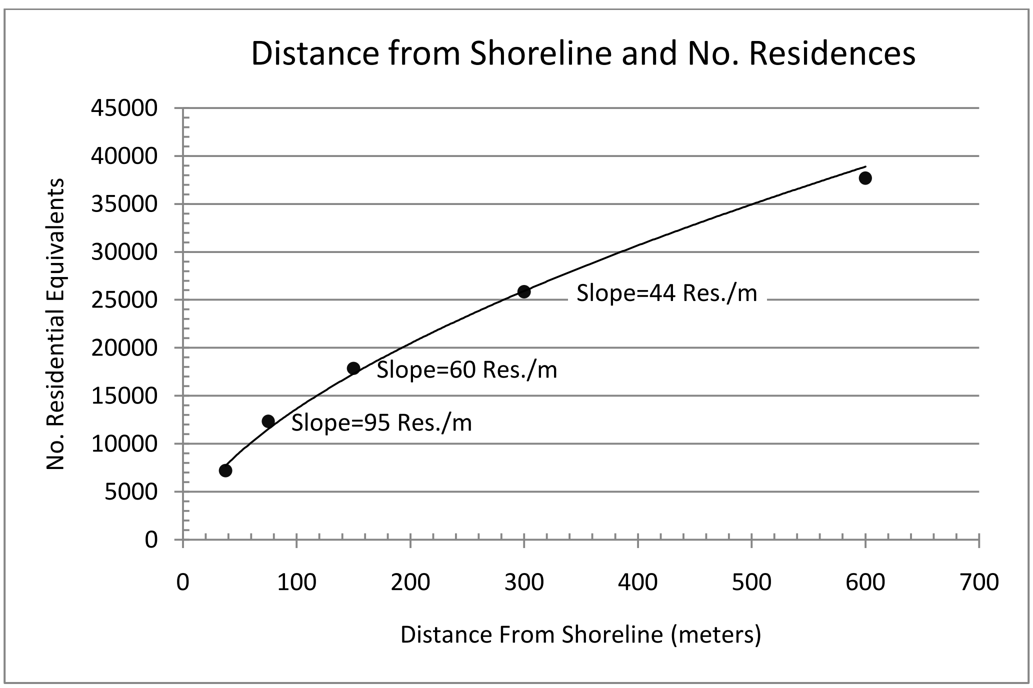


Figure A6. The relation between the distance from shoreline (meters) and the number of residences (exclusive area).

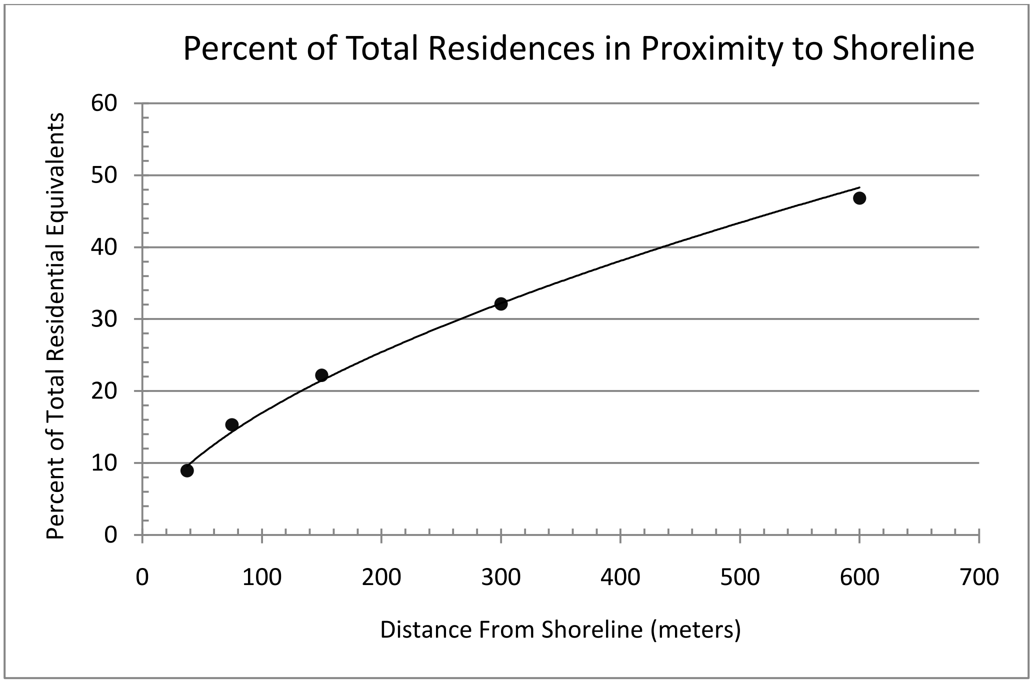


Figure A7. The percent representation of total residential equivalents (within exclusive area) based on distance from shoreline.

Table A2. Stream and residential-based nitrate loads for several catchments within the study area.

Catchment	Median July/August Discharge (ft3/s)	Median Nitrate Concentration (mg/L)	Catchment Area (ha)	Residences (No.)	Res./Ha	Stream Nitrate Load (kg/d)	On-Site System Load (kg/d)	Nitrate Attenuation (%)
Burley	14.17	0.697	2566	2398	0.93	24.16	48.85	51
Butler	0.04	1.500	124	141	1.13	0.16	2.87	94
Cranberry	9.93	0.096	3645	970	0.27	2.32	19.76	88
Deer	17.41	0.079	3748	161	0.04	3.36	3.28	0
Johns	11.95	0.220	2631	551	0.21	6.43	11.22	43
Judd	1.80	1.011	1212	339	0.28	4.45	6.91	36
Kennedy	5.40	0.351	5034	516	0.10	4.64	10.51	56
McAllister	==	1.010	6718	5047	0.75	==	102.81	==
McLane	3.90	0.158	2901	418	0.14	1.51	8.51	82
Mill	11.36	0.047	5207	388	0.07	1.31	7.90	83
Minter	==	0.438	3921	1929	0.49	==	39.29	==
Olalla	5.75	0.441	1283	669	0.52	6.20	13.63	54
Perry	0.62	0.383	1637	96	0.06	0.58	1.96	70
Purdy	1.91	0.340	938	433	0.46	1.59	8.82	82
Rocky	3.29	0.295	4763	1178	0.25	2.37	24.00	90
Schneider	1.20	0.127	1997	245	0.12	0.37	4.99	93
Sherwood	0.54	0.251	8576	1243	0.14	0.33	25.32	99
Shingle	2.09	0.880	805	296	0.37	4.50	6.03	25
Skookum	3.89	0.170	4084	61	0.01	1.62	1.24	0
Median	**3.89**	**0.30**	**2631**	**418**	**0.21**	**2.32**	**8.51**	**70**

*Shaded catchments were excluded from calculation of medians due to lack of flow measurements.

Appendix D. Rivers: Predicted and Observed Concentrations and Loads

Figures D-1 through D-3 compare observed and predicted concentrations and loads of various parameters for the Deschutes River.

Figure D-1. Predicted and observed concentrations (left column) and loads (right column) of nitrogen for the Deschutes River.

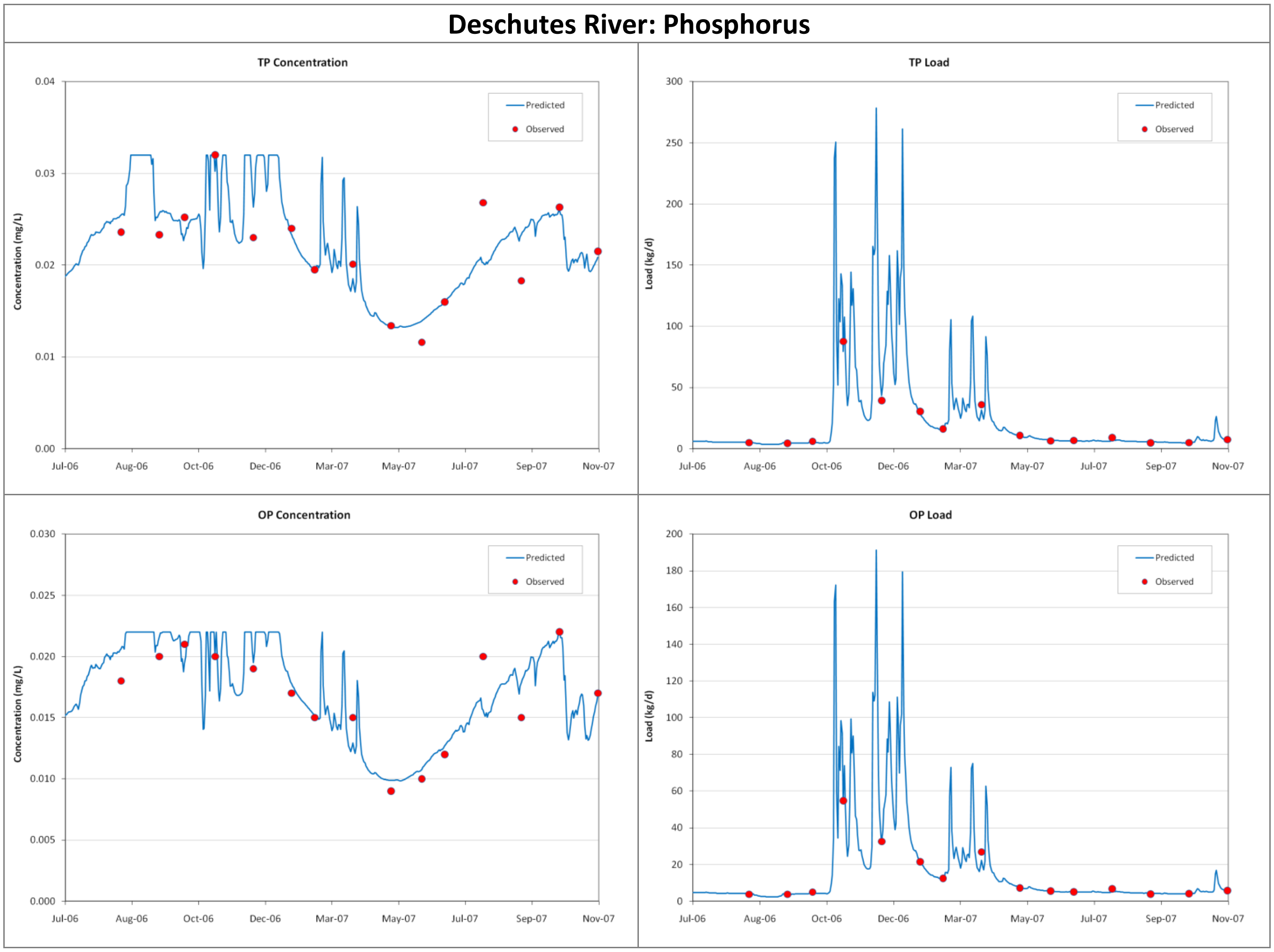


Figure D-2. Predicted and observed concentrations (left column) and loads (right column) of phosphorus for the Deschutes River.

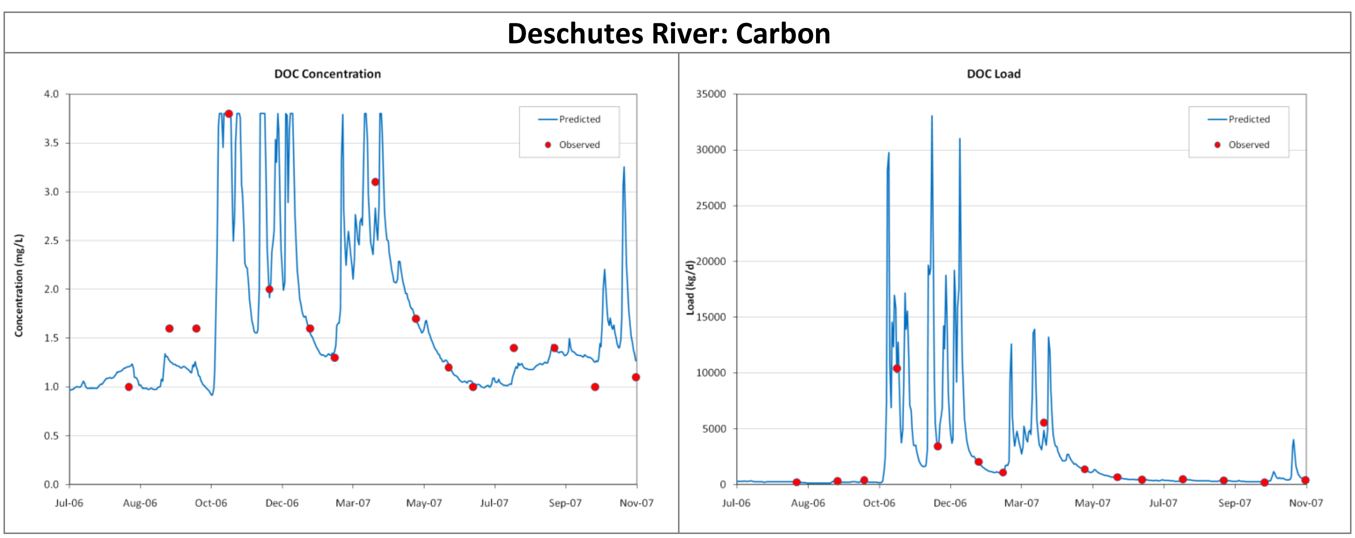


Figure D-3. Predicted and observed concentrations (left column) and loads (right column) of dissolved organic carbon for the Deschutes River.

Figures D-4 through D-6 compare observed and predicted concentrations and loads of various parameters for the Green River.

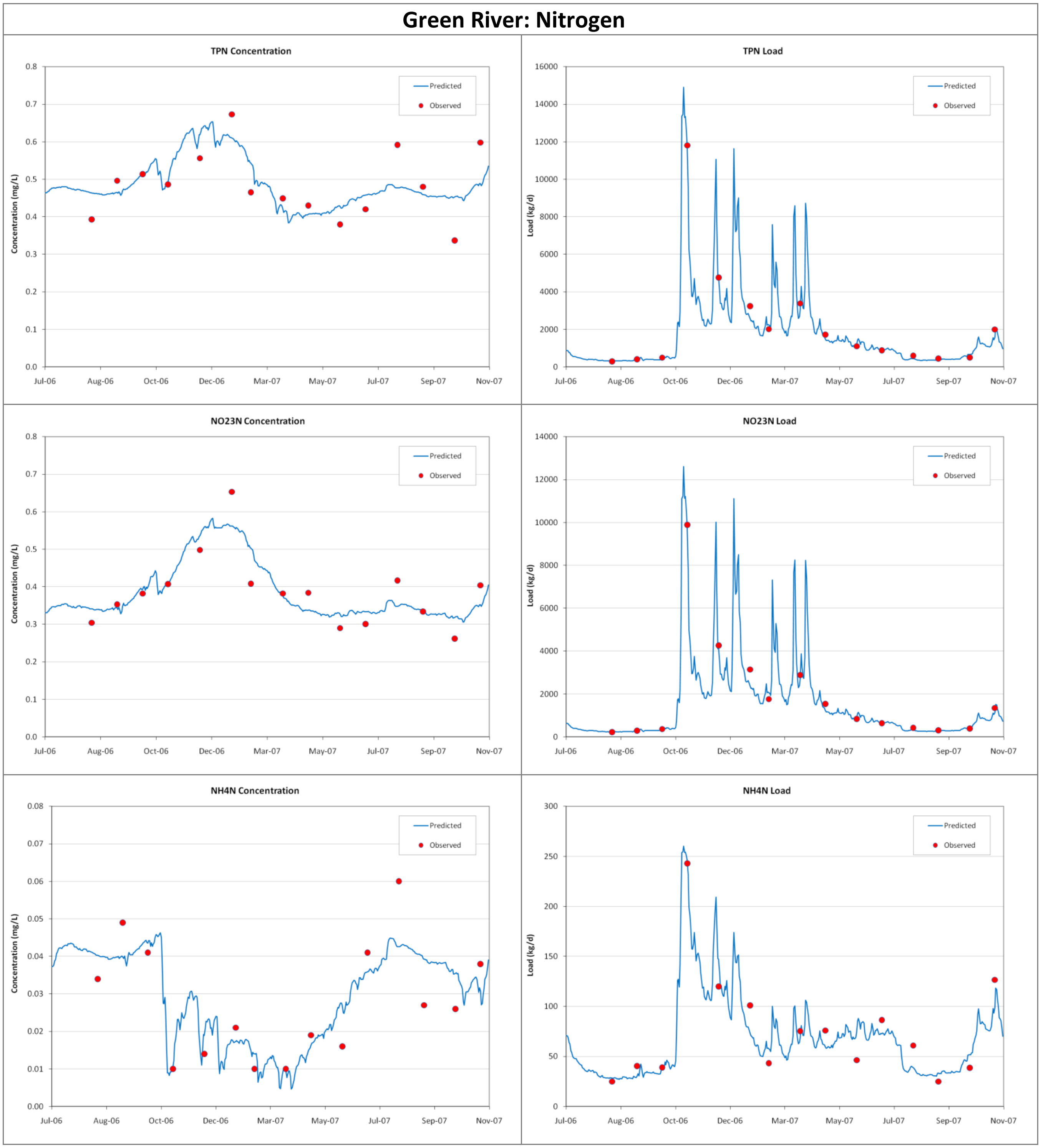


Figure D-4. Predicted and observed concentrations (left column) and loads (right column) of nitrogen for the Green River.

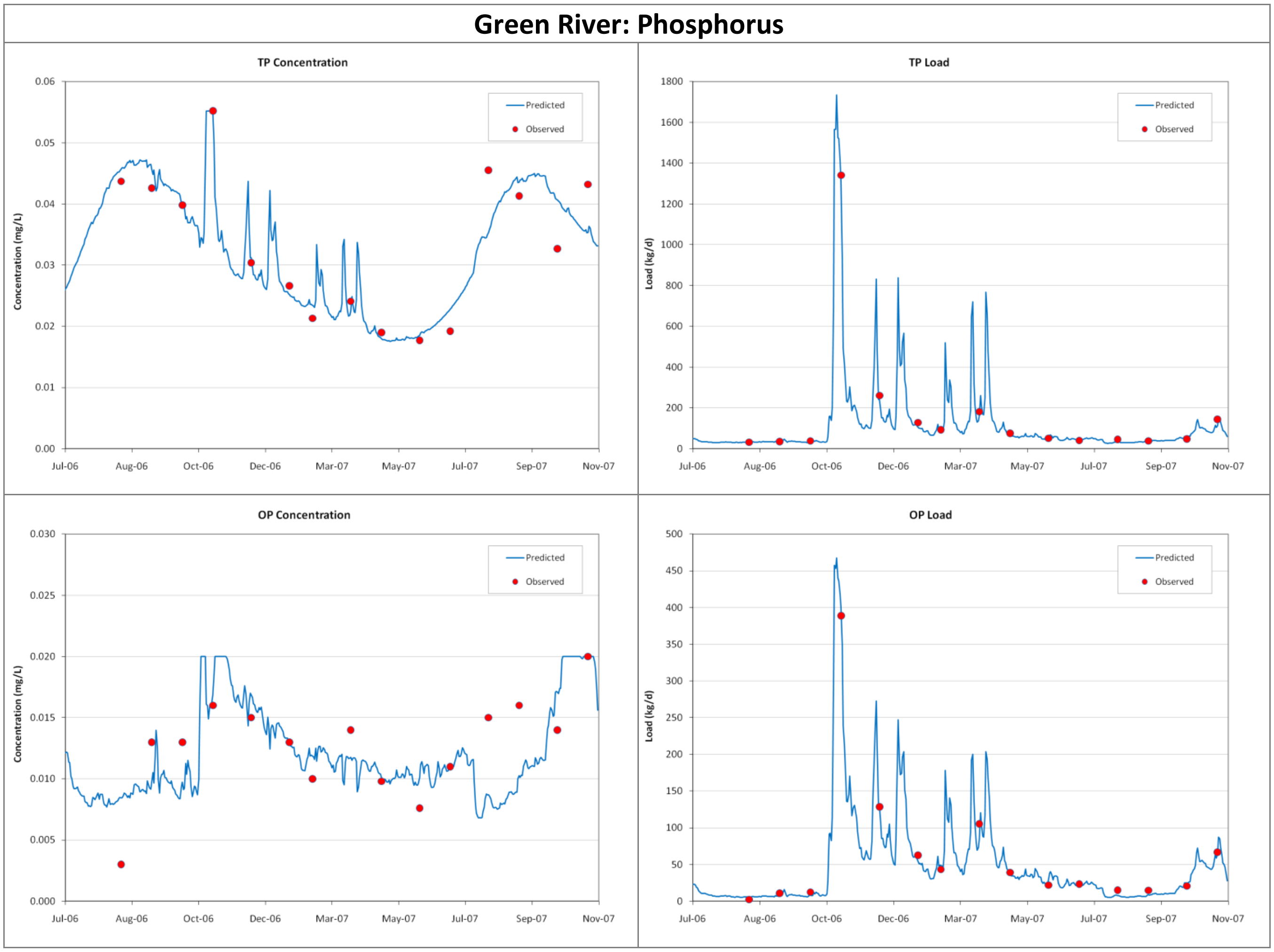


Figure D-5. Predicted and observed concentrations (left column) and loads (right column) of phosphorus for the Green River.

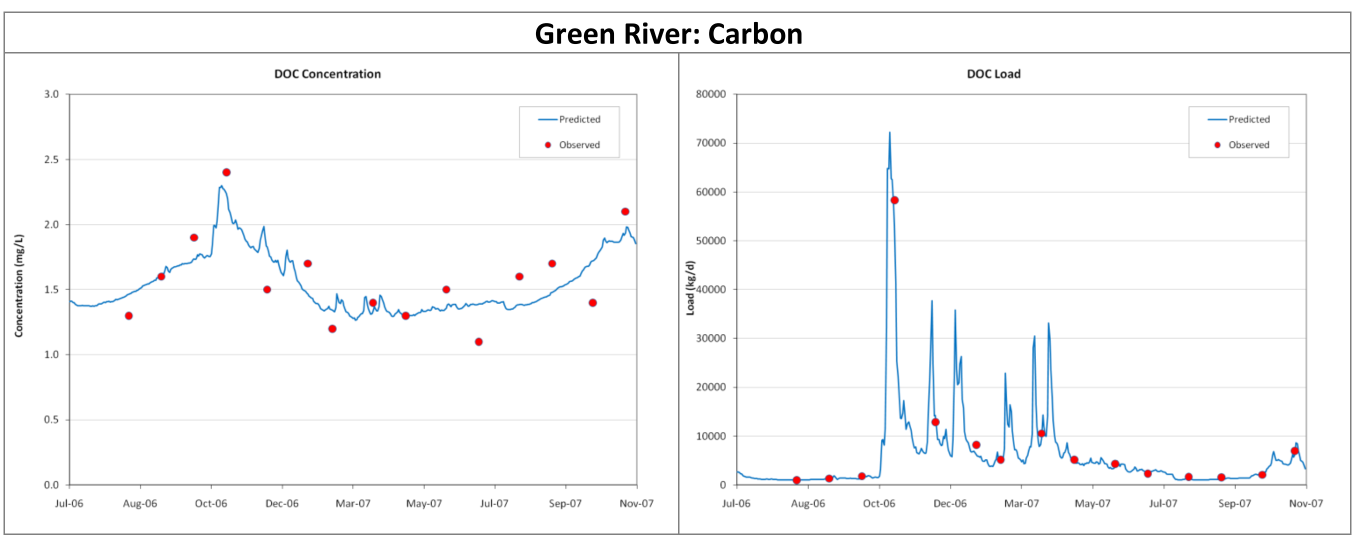


Figure D-6. Predicted and observed concentrations (left column) and loads (right column) of dissolved organic carbon for the Green River.

Figures D-7 through D-9 compare observed and predicted concentrations and loads of various parameters for the Nisqually River.

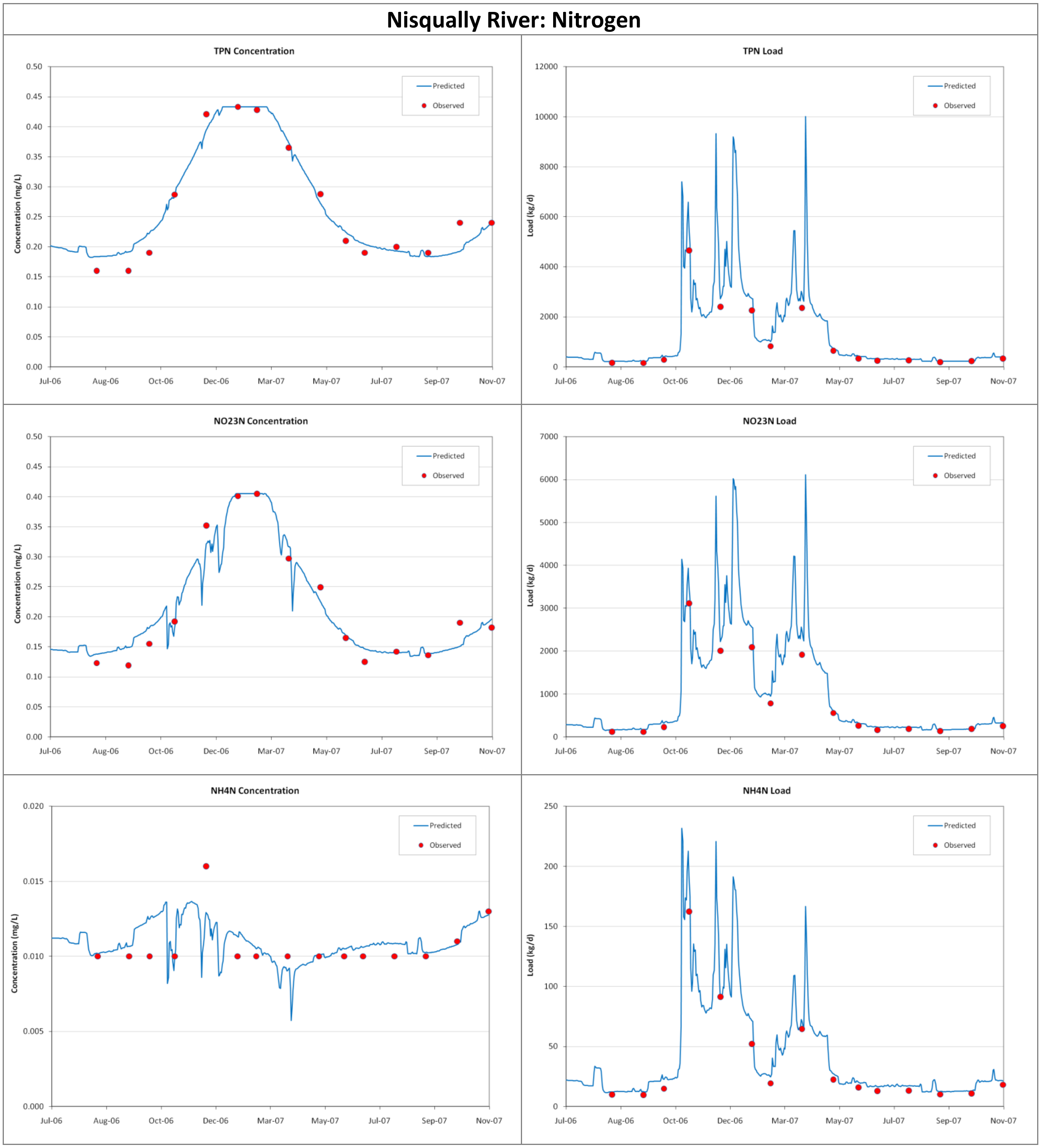


Figure D-7. Predicted and observed concentrations (left column) and loads (right column) of nitrogen for the Nisqually River.

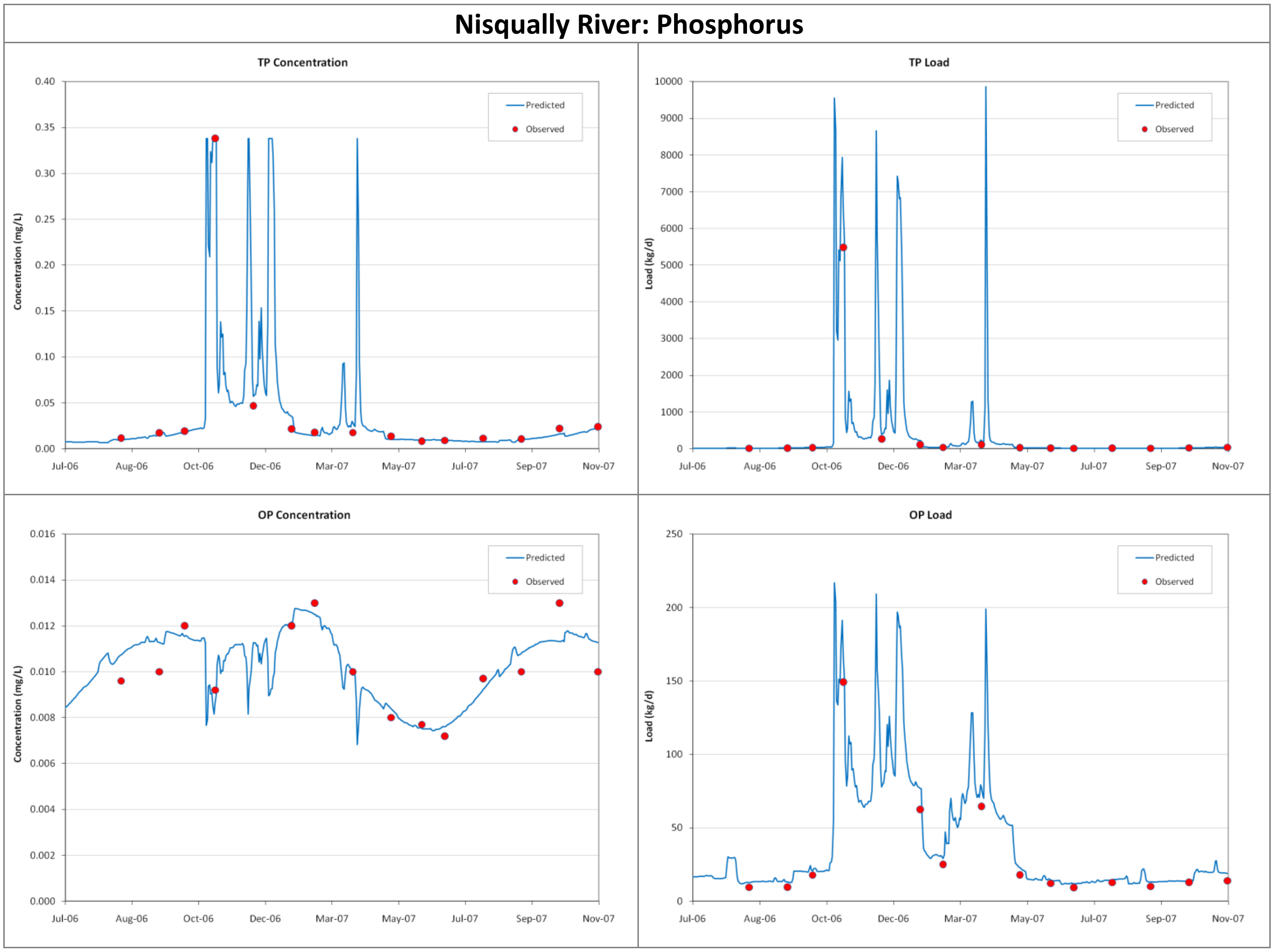


Figure D-8. Predicted and observed concentrations (left column) and loads (right column) of phosphorus for the Nisqually River.

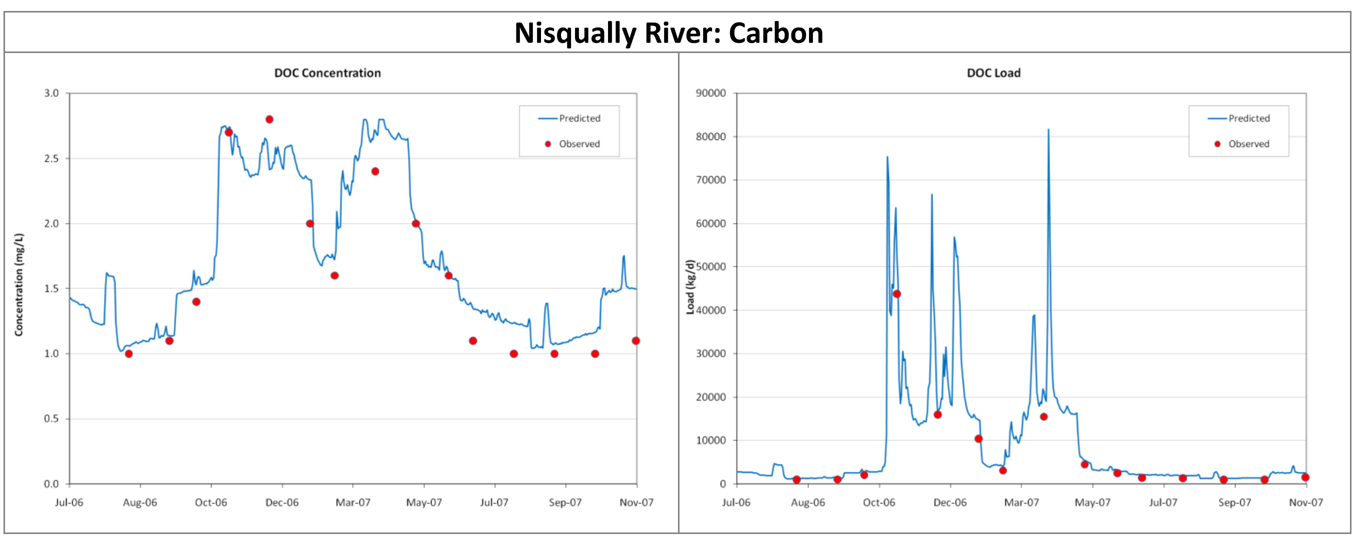


Figure D-9. Predicted and observed concentrations (left column) and loads (right column) of dissolved organic carbon for the Nisqually River.

Figures D-10 through D-12 compare observed and predicted concentrations and loads of various parameters for the Puyallup River.

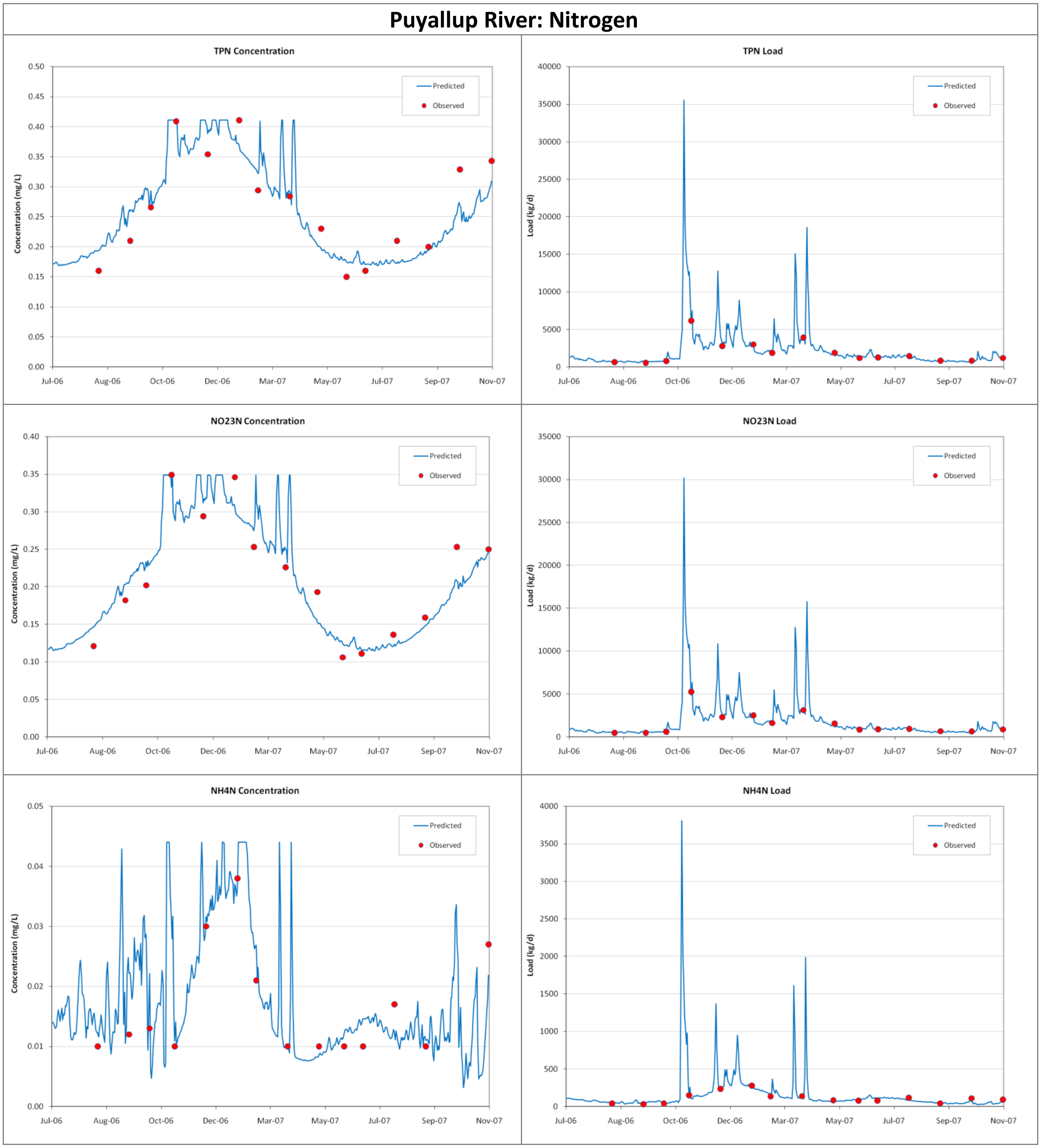


Figure D-10. Predicted and observed concentrations (left column) and loads (right column) of nitrogen for the Puyallup River.

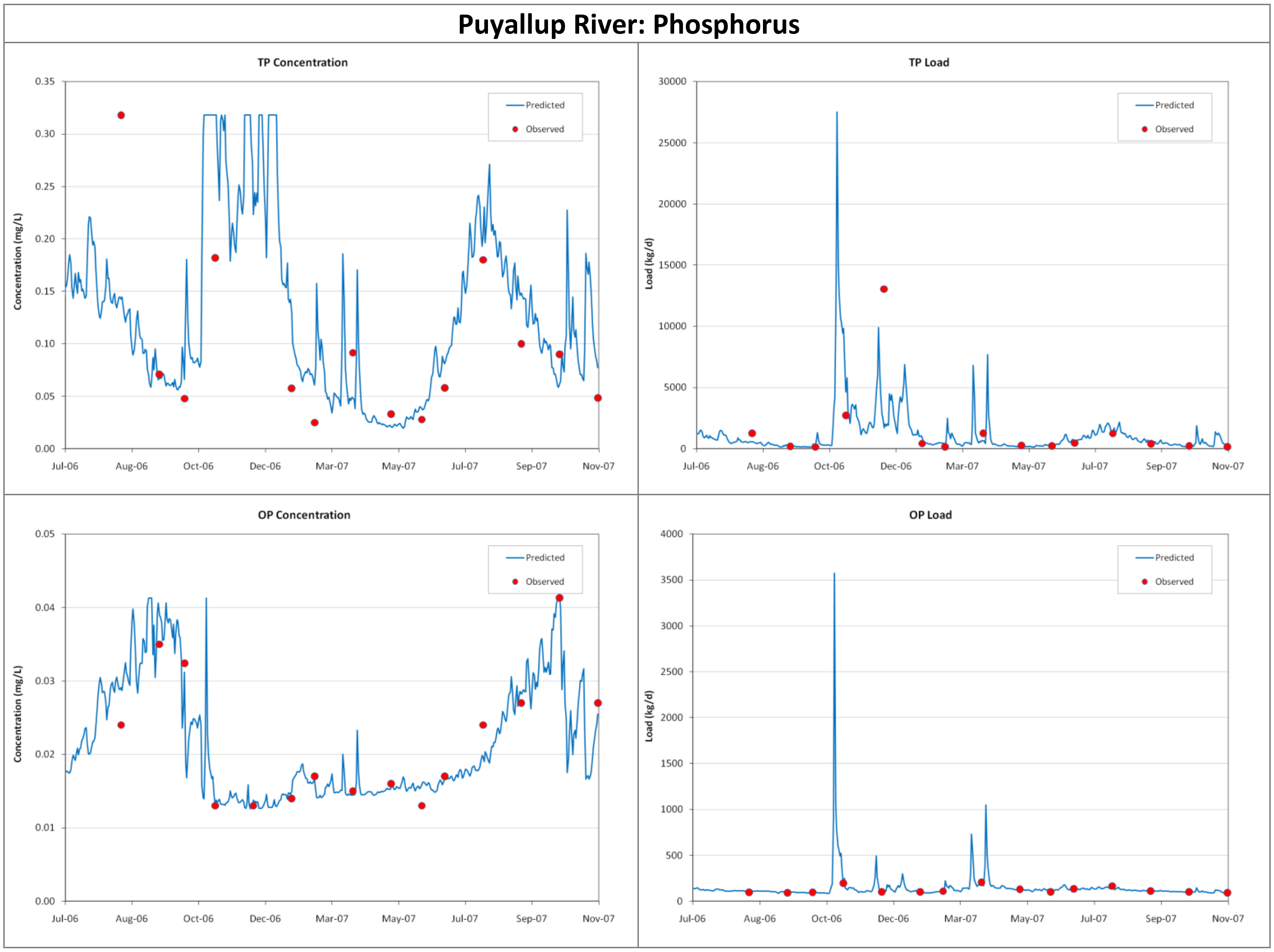


Figure D-11. Predicted and observed concentrations (left column) and loads (right column) of phosphorus for the Puyallup River.

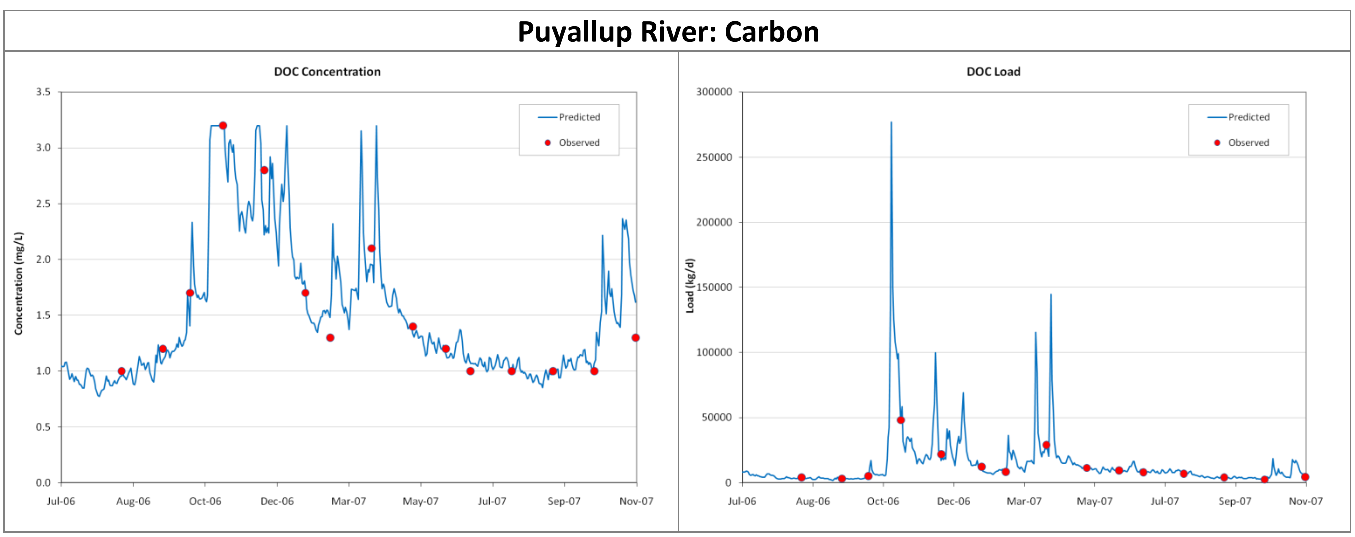


Figure D-12. Predicted and observed concentrations (left column) and loads (right column) of dissolved organic carbon for the Puyallup River.

Table D-1 presents the average difference and average root mean square error (RMSE) between predicted and observed concentrations of various parameters for each rivers and streams where monitoring took place for wither 15 or four months.

Table D-1. Average difference and average RMSE between predicted and observed concentrations of various parameters for stations that were monitored for 15 months and stations that were monitored for 4 months.

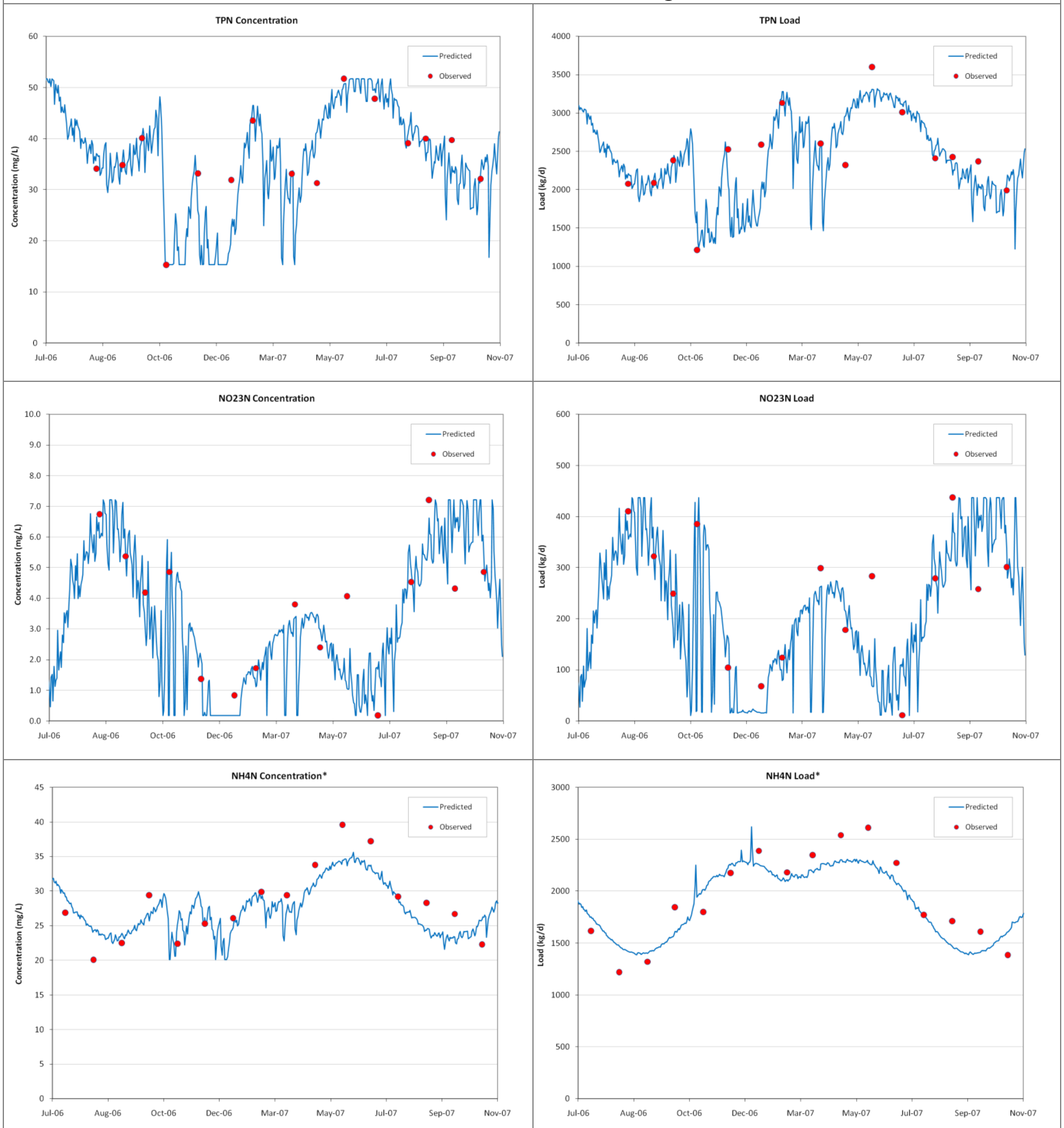
Difference between Predicted and Observed Concentrations						
Stream/River Name	**NO23N** mg/L	**NH4N** mg/L	**TPN** mg/L	**OP** mg/L	**TP** mg/L	**DOC** mg/L
15 Month Stations						
Burley	-0.017	-0.003	-0.031	0.002	0.004	-0.974
Chambers	0.000	0.000	0.001	0.000	0.000	0.000
Coulter	-0.007	0.008	-0.007	0.001	0.001	-0.084
Deschutes	0.015	0.000	0.010	0.000	0.000	-0.043
Goldsborough	0.000	0.000	0.000	0.000	0.000	0.274
Green	0.002	0.000	0.002	0.000	0.000	-0.008
Kennedy	-0.001	-0.013	-0.018	-0.003	-0.004	0.023
Lake Washington	-0.005	0.001	0.007	0.000	0.001	-0.052
McAllister	0.000	0.000	-0.006	-0.001	0.000	-0.013
McLane	0.035	0.001	0.032	0.000	0.000	-0.566
Minter	0.000	-0.005	0.000	0.000	0.000	0.010
Nisqually	0.002	0.000	0.002	0.000	0.001	0.122
Perry	0.064	0.003	0.082	0.001	0.004	-1.316
Puyallup	0.000	0.001	0.000	0.000	0.009	-0.040
Rocky	0.025	-0.003	0.050	-0.004	-0.001	0.186
Sherwood	-0.033	-0.014	-0.051	-0.008	-0.001	0.267
Sinclair Dyes	0.000	0.000	-0.001	0.000	0.000	-0.003
Skookum	0.076	0.000	0.041	0.000	0.001	-0.161
Woodard	-0.076	0.000	0.039	0.000	0.003	0.063
Woodland	-0.006	0.001	0.007	0.000	0.000	0.023
Avg. Difference	**0.004**	**-0.001**	**0.008**	**-0.001**	**0.001**	**-0.115**
4 Month Stations						
Butler	-1.192	0.010	-1.158	-0.022	-0.006	-2.140
Campbell	0.203	0.010	0.187	0.000	0.009	-3.473
Cranberry	0.162	0.003	0.156	-0.005	0.007	-0.911
Curley	0.105	0.009	0.047	0.005	0.013	-3.066
Des Moines	-0.534	0.006	-0.601	-0.048	-0.037	-3.477
Ellis	-0.676	0.006	-0.674	-0.027	-0.020	-2.466
Goodnough	-2.451	0.010	-2.334	0.001	0.007	-1.366
Hylebos	-0.655	-0.053	-0.774	-0.073	-0.081	-5.027
Johns	0.031	-0.006	0.021	-0.008	0.006	-1.123
Judd	-0.684	0.010	-0.715	-0.025	-0.012	-3.940
Mill	0.231	0.010	0.220	0.006	0.018	-1.798
Miller	-0.813	0.010	-0.849	-0.041	-0.032	-3.902
Mission	-0.960	0.003	-1.026	-0.081	-0.085	-3.391
Moxlie	-0.472	0.000	-0.445	-0.041	-0.037	-1.491
Olalla	-0.148	0.010	-0.137	-0.011	0.001	-2.591
Purdy	-0.015	0.010	-0.017	-0.014	-0.001	-2.116
Shingle Mill	-0.604	0.010	-0.564	-0.037	-0.021	-2.152
Avg. Difference	**-0.498**	**0.004**	**-0.510**	**-0.025**	**-0.016**	**-2.614**

Root Mean Square Error between Predicted and Observed Concentrations						
Stream/River Name	**NO23N** mg/L	**NH4N** mg/L	**TPN** mg/L	**OP** mg/L	**TP** mg/L	**DOC** mg/L
15 Month Stations						
Burley	0.039	0.007	0.057	0.004	0.013	2.327
Chambers	0.137	0.003	0.105	0.005	0.003	0.249
Coulter	0.010	0.014	0.018	0.004	0.004	0.828
Deschutes	0.041	0.001	0.048	0.002	0.003	0.165
Goldsborough	0.008	0.000	0.021	0.001	0.001	1.059
Green	0.048	0.007	0.062	0.003	0.004	0.195
Kennedy	0.022	0.045	0.046	0.005	0.007	0.053
Lake Washington	0.014	0.006	0.058	0.000	0.006	0.316
McAllister	0.051	0.011	0.304	0.007	0.015	0.176
McLane	0.066	0.013	0.070	0.001	0.004	1.578
Minter	0.017	0.037	0.052	0.007	0.010	1.012
Nisqually	0.020	0.001	0.021	0.001	0.006	0.218
Perry	0.123	0.006	0.145	0.002	0.006	1.767
Puyallup	0.025	0.006	0.033	0.002	0.067	0.200
Rocky	0.037	0.006	0.068	0.005	0.002	0.252
Sherwood	0.052	0.043	0.091	0.014	0.009	0.859
Sinclair Dyes	0.022	0.003	0.024	0.001	0.004	0.152
Skookum	0.133	0.002	0.085	0.001	0.002	0.370
Woodard	0.111	0.001	0.108	0.001	0.005	3.772
Woodland	0.229	0.012	0.177	0.002	0.002	0.243
Avg, RMSE	**0.060**	**0.011**	**0.080**	**0.003**	**0.009**	**0.790**
4 Month Stations						
Butler	1.195	0.012	1.160	0.022	0.010	4.812
Campbell	0.204	0.013	0.188	0.003	0.009	4.584
Cranberry	0.164	0.018	0.157	0.005	0.007	1.312
Curley	0.123	0.010	0.075	0.005	0.013	3.659
Des Moines	0.592	0.012	0.655	0.049	0.038	5.269
Ellis	0.691	0.009	0.685	0.028	0.021	4.414
Goodnough	2.454	0.012	2.339	0.002	0.018	2.951
Hylebos	0.665	0.054	0.775	0.074	0.081	8.282
Johns	0.036	0.033	0.056	0.008	0.008	2.259
Judd	0.693	0.013	0.718	0.026	0.013	5.640
Mill	0.234	0.013	0.222	0.007	0.018	2.647
Miller	0.865	0.012	0.900	0.042	0.033	5.710
Mission	0.980	0.009	1.038	0.081	0.086	5.829
Moxlie	0.475	0.008	0.448	0.041	0.037	3.620
Olalla	0.157	0.012	0.141	0.011	0.002	3.924
Purdy	0.104	0.012	0.127	0.014	0.004	3.805
Shingle Mill	0.604	0.012	0.564	0.037	0.022	4.017
Avg. RMSE	**0.602**	**0.016**	**0.603**	**0.027**	**0.025**	**4.279**

Appendix E. WWTPs: Predicted and Observed Concentrations and Loads

Figures E-1 through E-4 compare observed and predicted concentrations and loads of various parameters for the Chambers Creek WWTP.

Chambers Creek WWTP: Nitrogen



* Observed NH4N concentrations and load data shown in the bottom two figures are from the DMR for Chambers Creek WWTP, and were used to the develop the NH4N regression estimates instead of the data Ecology collected at this plant.

Figure E-1. Predicted and observed concentrations (left column) and loads (right column) of nitrogen for the Chambers Creek WWTP.

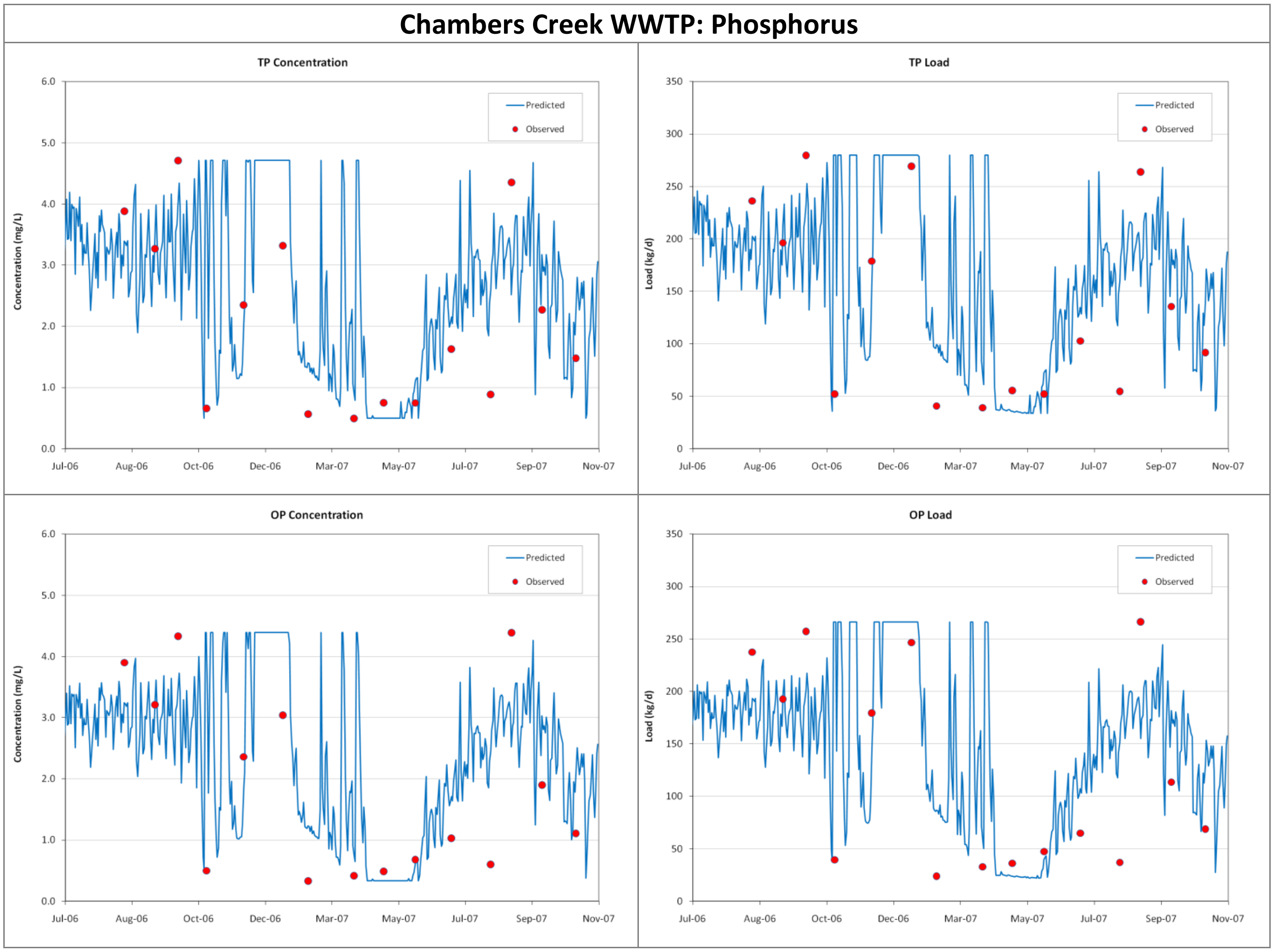


Figure E-2. Predicted and observed concentrations (left column) and loads (right column) of phosphorus for the Chambers Creek WWTP.

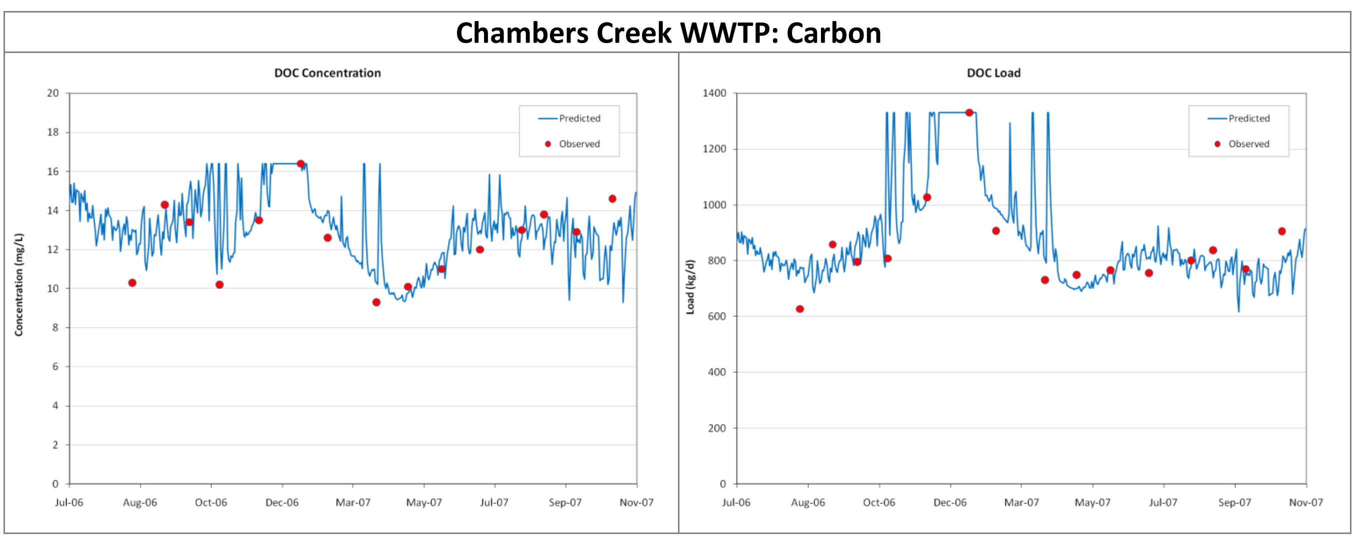


Figure E-3. Predicted and observed concentrations (left column) and loads (right column) of dissolved organic carbon for the Chambers Creek WWTP.

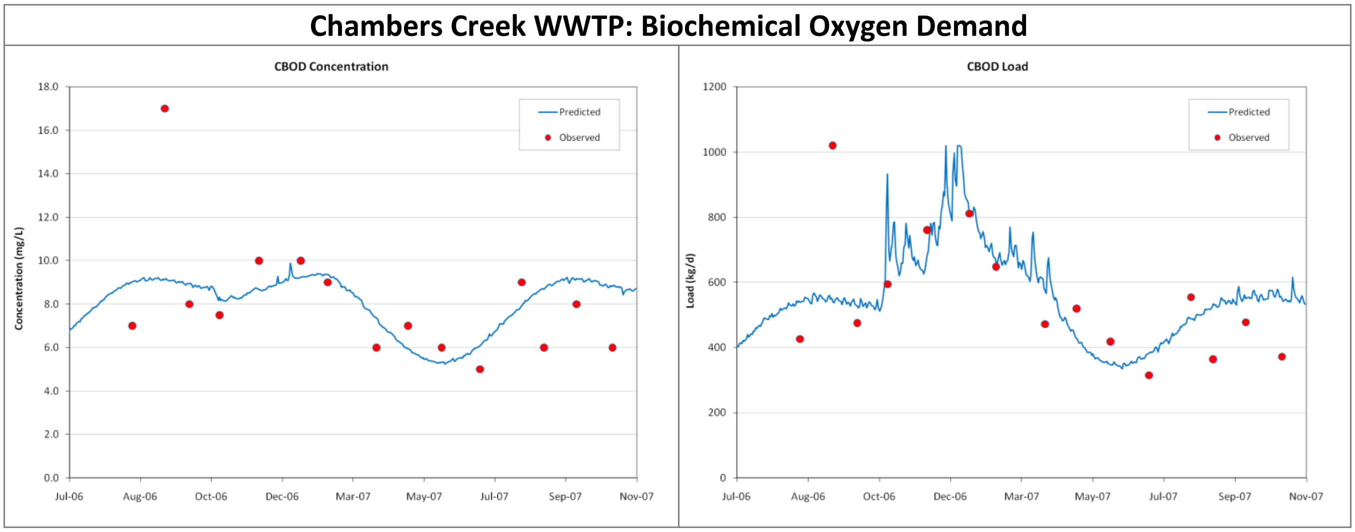


Figure E-4. Predicted and observed concentrations (left column) and loads (right column) of CBOD for the Chambers Creek WWTP.

Figures E-5 through E-8 compare observed and predicted concentrations and loads of various parameters for the South King WWTP.

South King WWTP: Nitrogen

* Observed NH4N concentrations and load data shown in the bottom two figures were sent to Ecology by the South King WWTP, and were used to the develop the NH4N regression estimates instead of the data Ecology collected at this plant.

Figure E-5. Predicted and observed concentrations (left column) and loads (right column) of nitrogen for the South King WWTP.

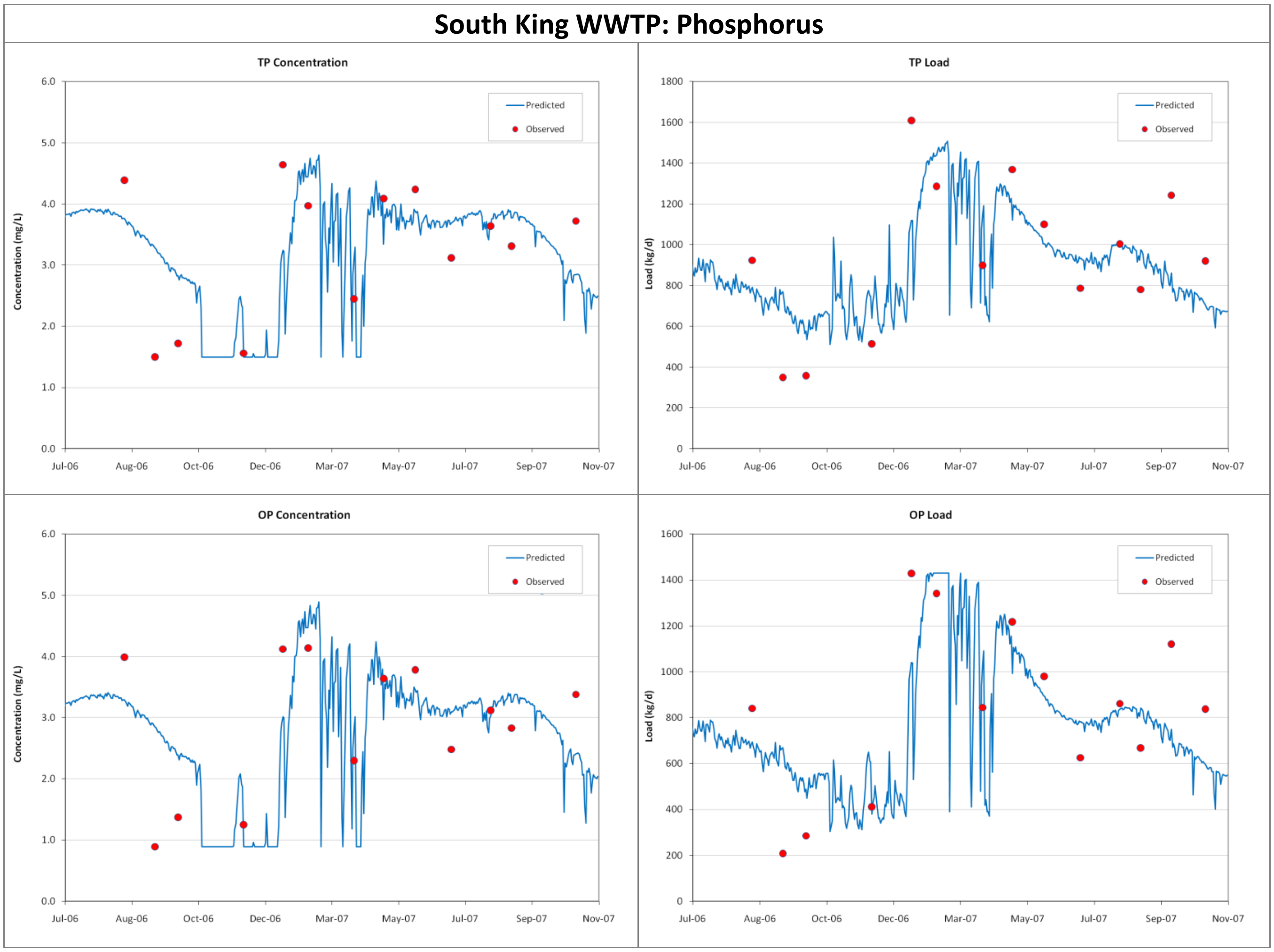


Figure E-6. Predicted and observed concentrations (left column) and loads (right column) of phosphorus for the South King WWTP.

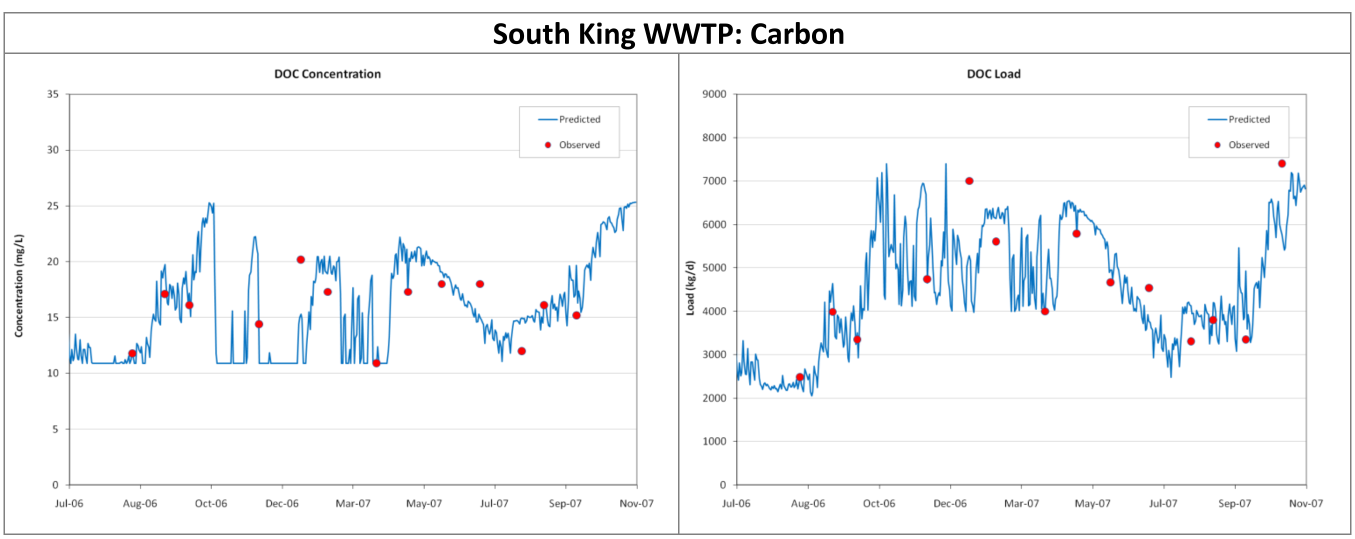


Figure E-7. Predicted and observed concentrations (left column) and loads (right column) of dissolved organic carbon for the South King WWTP.

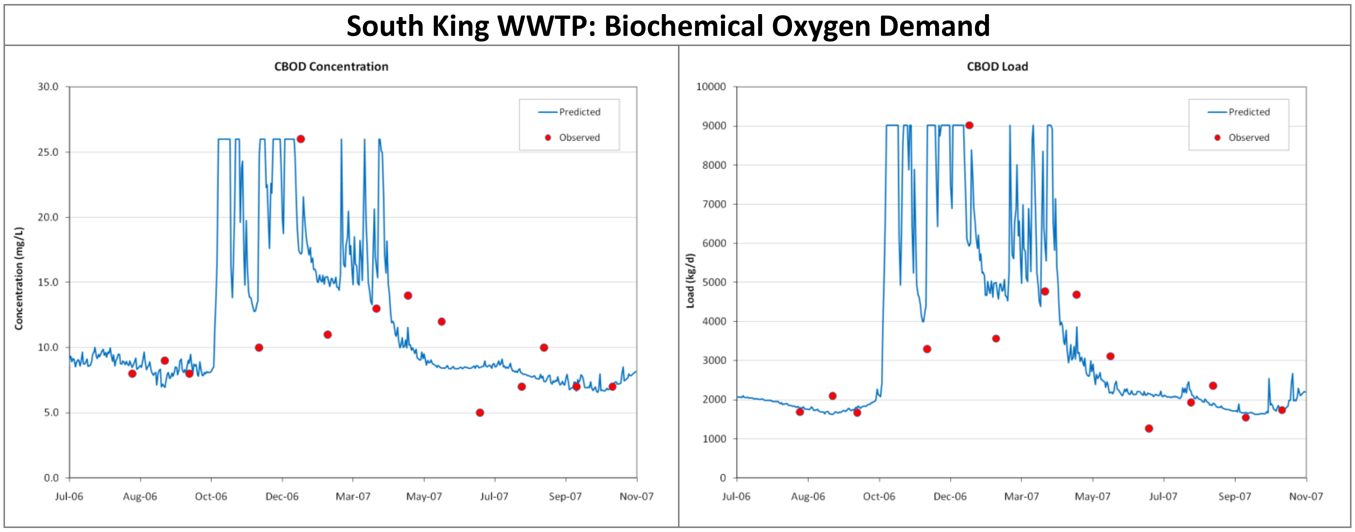


Figure E-8. Predicted and observed concentrations (left column) and loads (right column) of CBOD for the South King WWTP.

Figures E-9 through E-12 compare observed and predicted concentrations and loads of various parameters for the Tacoma-Central WWTP.

Figure E-9. Predicted and observed concentrations (left column) and loads (right column) of nitrogen for the Tacoma-Central WWTP.

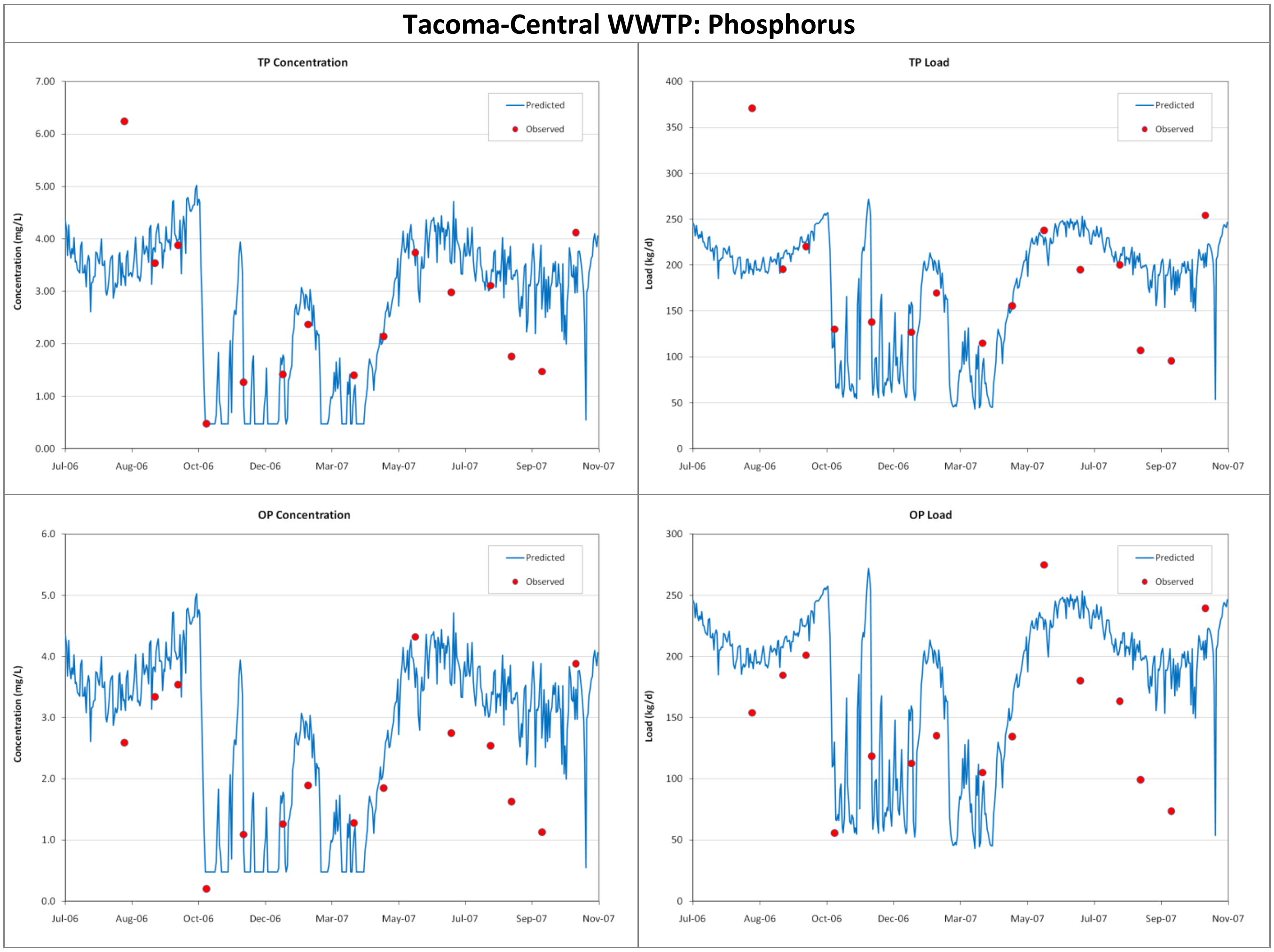


Figure E-10. Predicted and observed concentrations (left column) and loads (right column) of phosphorus for the Tacoma-Central WWTP.

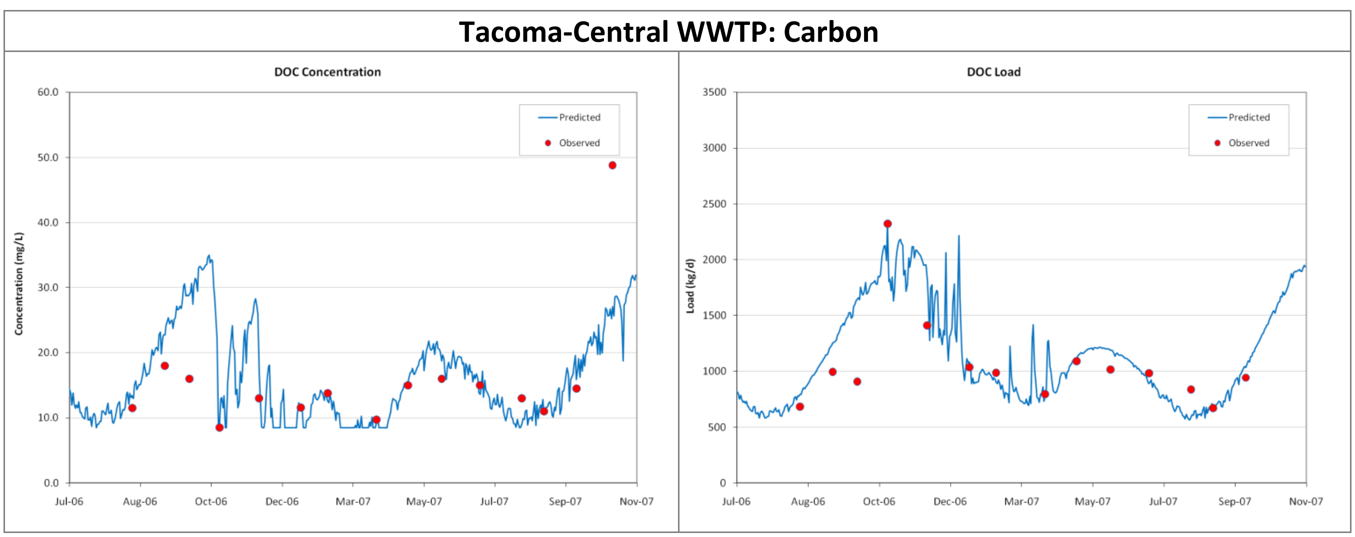


Figure E-11. Predicted and observed concentrations (left column) and loads (right column) of dissolved organic carbon for the Tacoma-Central WWTP.

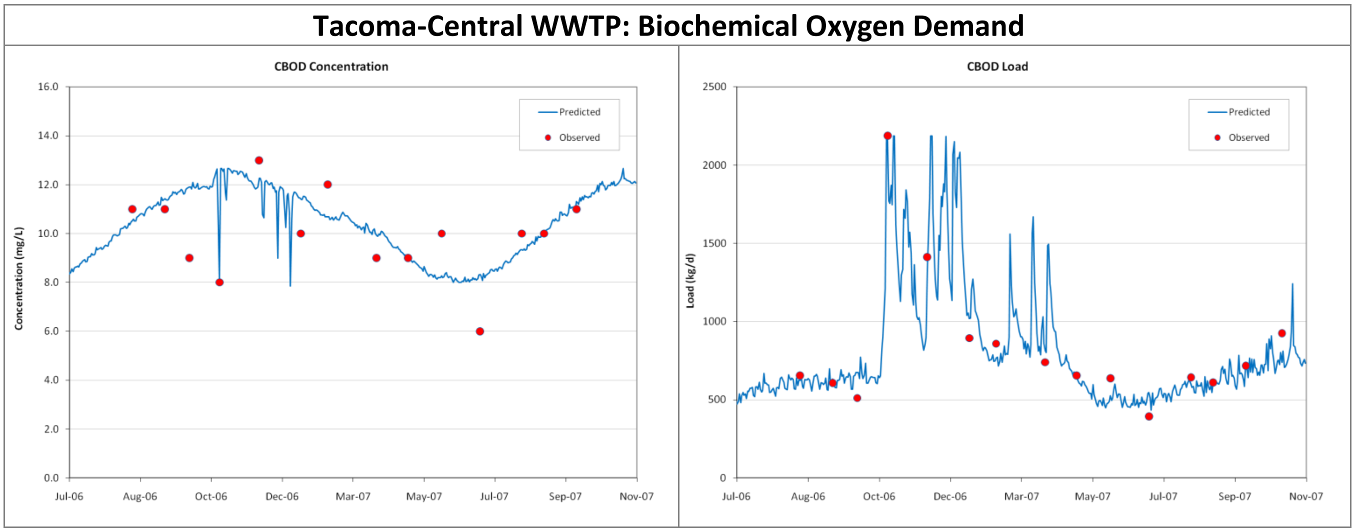


Figure E-12. Predicted and observed concentrations (left column) and loads (right column) of CBOD for the Tacoma-Central WWTP.

Figures E-13 through E-16 compare observed and predicted concentrations and loads of various parameters for the West Point WWTP.

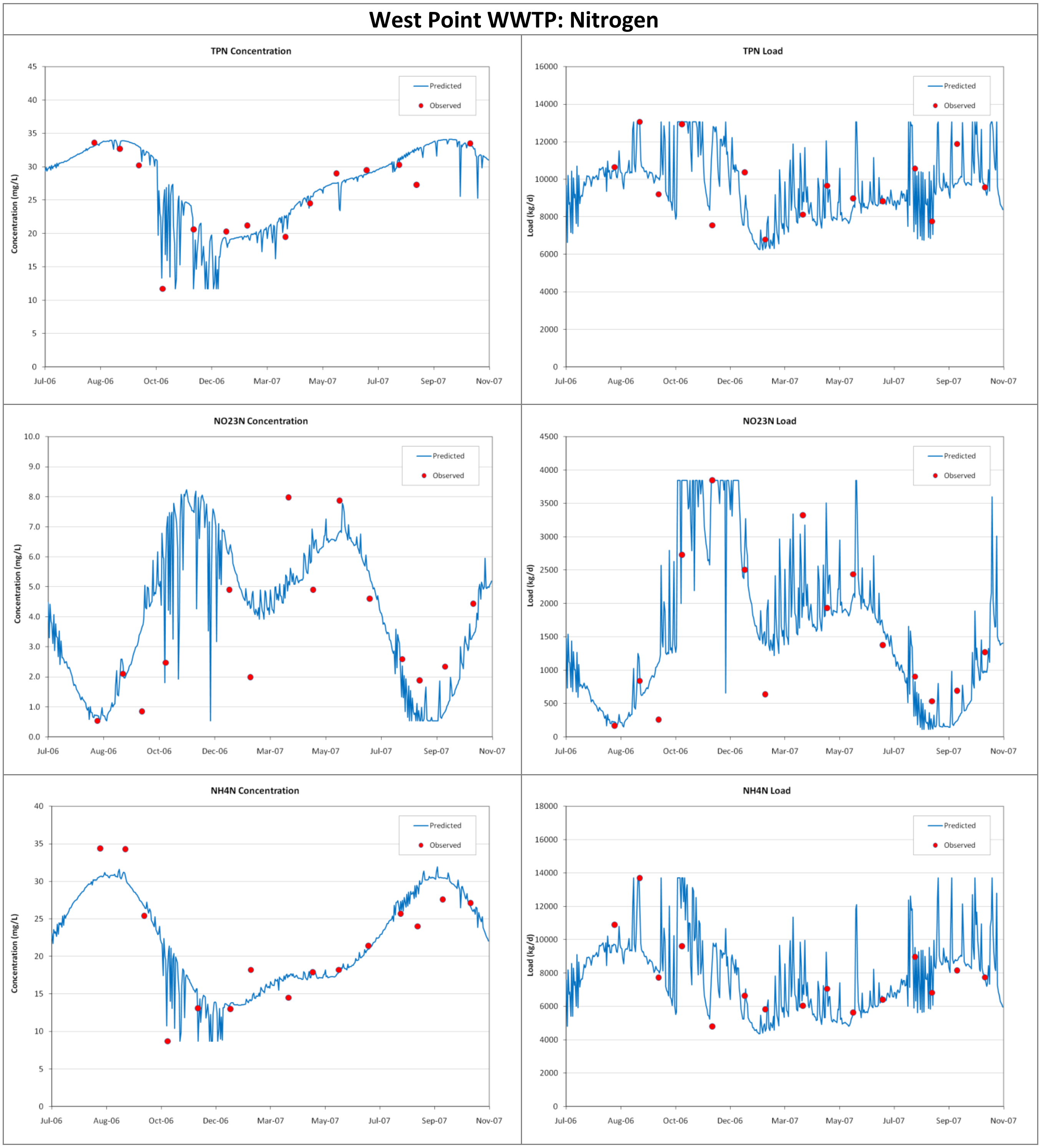


Figure E-13. Predicted and observed concentrations (left column) and loads (right column) of nitrogen for the West Point WWTP.

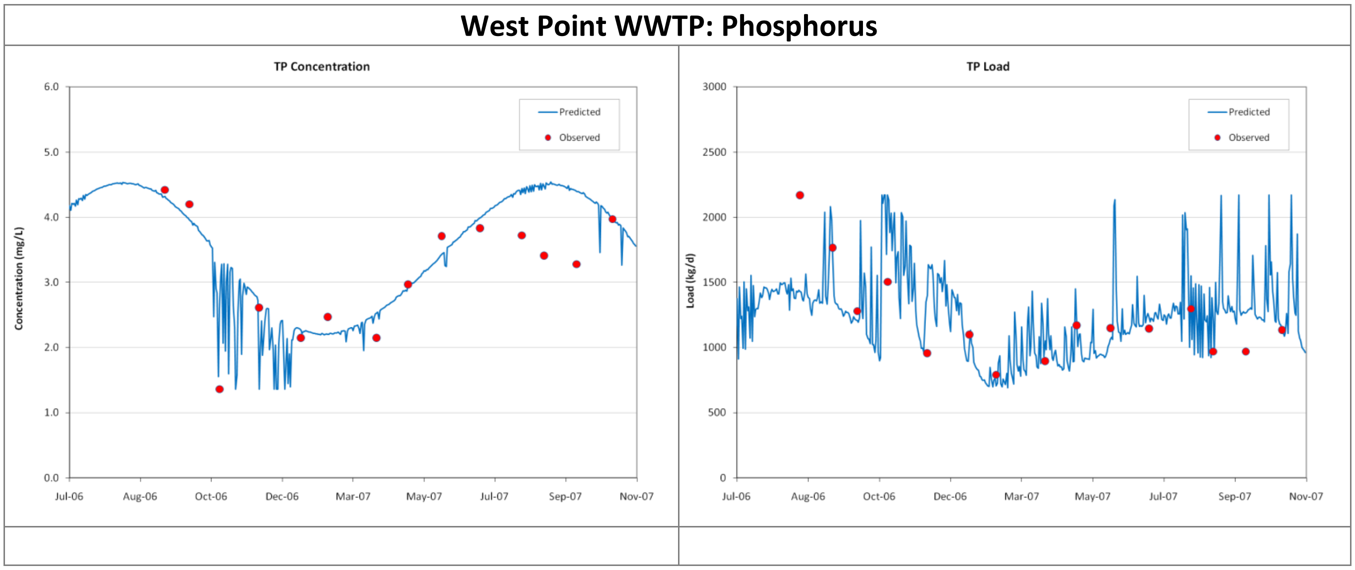


Figure E-14. Predicted and observed concentrations (left column) and loads (right column) of phosphorus for the West Point WWTP.

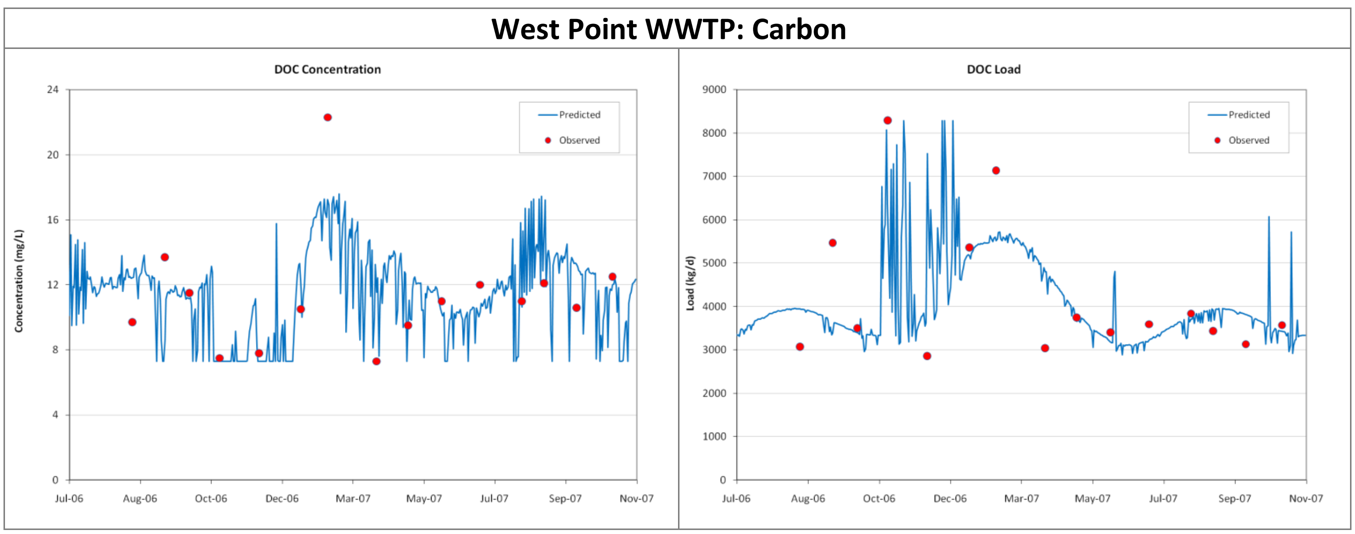


Figure E-15. Predicted and observed concentrations (left column) and loads (right column) of dissolved organic carbon for the West Point WWTP.

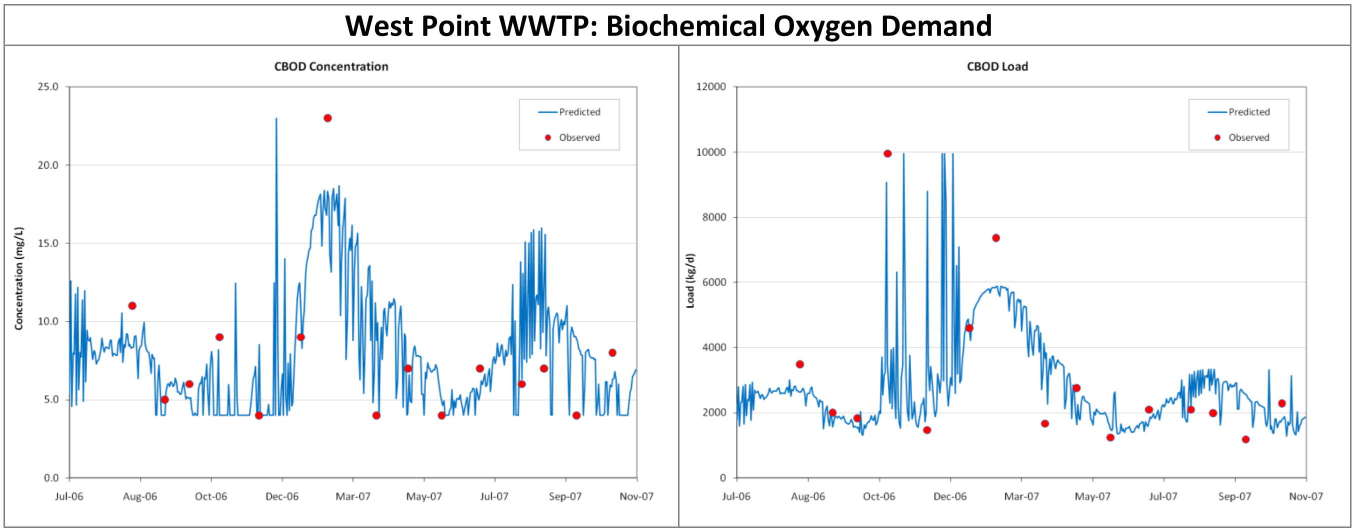


Figure E-16. Predicted and observed concentrations (left column) and loads (right column) of CBOD for the West Point WWTP.

Table E-1 presents the average difference and average root mean square error (RMSE) between predicted and observed concentrations of various parameters for each WWTP where monitoring took place for either 15 or three months.

Table E-1. Average difference and average RMSE between predicted and observed concentrations of various parameters for WWTPs that were monitored for 15 months and WWTPs that were monitored for 4 months.

Difference between Predicted and Observed Concentrations

WWTP Name	NO23N mg/L	NH4N mg/L	TPN mg/L	OP mg/L	TP mg/L	DOC mg/L	CBOD mg/L
15 Month WWTPs							
Boston Harbor	1.438	-0.061	1.170	-0.205	0.191	0.008	-0.612
Bremerton	0.172	-1.016	-0.337	-0.027	0.026	0.045	0.102
Chambers	-0.416	0.000*	-0.291	0.468	0.506	0.608	0.040
Gig Harbor	-0.004	0.378	0.296	0.251	0.318	1.472	0.826
Lakota	0.023	-0.453	-0.627	-0.259	-0.338	0.098	-0.623
LOTT	-0.172	-0.079	-0.398	0.163	0.020	0.025	0.058
Manchester	-0.131	0.098	-0.080	-0.037	-0.037	-0.165	-0.081
Midway	-0.247	-0.369	-0.246	-0.016	-0.061	0.231	0.267
Port Orchard	0.553	-0.433	-0.012	-0.077	-0.036	0.024	0.270
Redondo	-0.478	-0.148	-0.466	-0.046	-0.074	-0.246	0.286
Shelton	0.076	0.373	0.181	0.116	0.043	0.528	0.505
South King	0.072	0.000*	-0.861	-0.102	-0.083	-0.273	0.586
Tacoma-Central	0.007	-0.175	-0.125	-0.030	-0.015	-0.004	0.036
Tacoma-North	0.009	-0.648	-0.161	0.001	0.000	-0.398	-0.713
Tamoshan	0.276	-0.319	0.038	-0.298	-0.001	0.236	-0.028
West Point	-0.122	0.433	0.046	0.045	0.020	-0.080	0.091
Avg. Difference	**0.066**	**-0.151**	**-0.117**	**-0.003**	**0.030**	**0.132**	**0.063**
3 Month WWTPs - Medium Template							
Fort Lewis	-0.061*	-0.248*	3.876	-1.319	-0.465	-5.856	-3.075
Miller	7.093	-6.229	-0.190	0.106	0.313	-9.239	-1.741
Salmon	-1.184	-6.229	11.79	0.106	0.313	-2.156	1.425
Avg. Difference	**1.950**	**-4.235**	**5.160**	**-0.369**	**0.053**	**-5.750**	**-1.130**
3 Month WWTPs - Small Template							
Bainbridge Kitsap	-21.75	2.617	-19.98	-0.719	-0.555	5.947	0.807
Harstene	2.782	1.276	5.565	-0.467	1.153	4.935	2.361
Kitsap Kingston	-6.252	2.341	-3.712	1.163	1.806	2.268	2.361
Rustlewood	5.027	-8.745	-3.378	0.567	0.856	4.935	2.361
Seashore Villa	-4.487	-6.694	-12.63	1.209	-0.840	-4.853	-3.193
Suquamish	5.069	-25.60	-20.88	3.744	4.251	-0.398	2.361
Vashon	-7.742	2.697	-4.392	-1.430	-0.841	-0.198	2.361
Avg. Difference	**-3.908**	**-4.587**	**-8.488**	**0.581**	**0.833**	**1.805**	**1.345**
3 Month WWTPs - Other							
Carlyon	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Simpson Kraft	0.047	-0.004	0.042	0.114	0.215	0.941	--

Root Mean Square Error between Predicted and Observed Concentrations

WWTP Name	NO23N mg/L	NH4N mg/L	TPN mg/L	OP mg/L	TP mg/L	DOC mg/L	CBOD mg/L
15 Month WWTPs							
Boston Harbor	4.764	8.364	6.648	1.672	0.688	1.106	4.441
Bremerton	1.927	8.476	7.424	0.960	0.746	1.040	2.219
Chambers	1.667	2.856*	4.583	1.392	1.375	2.017	2.478
Gig Harbor	2.783	4.714	3.473	1.263	1.386	4.813	3.415
Lakota	0.399	4.523	4.528	0.959	0.878	2.062	2.611
LOTT	0.615	0.702	1.467	1.227	0.573	1.603	0.284
Manchester	3.054	1.732	2.672	0.886	0.407	1.029	1.219
Midway	1.716	1.467	1.476	0.604	0.289	1.734	0.900
Port Orchard	2.184	8.623	8.130	1.837	1.764	2.390	4.490
Redondo	2.570	2.010	4.108	0.402	0.246	1.749	2.022
Shelton	1.712	2.988	4.037	0.720	0.823	6.261	4.300
South King	0.581	4.942*	4.156	0.984	1.009	3.051	5.126
Tacoma-Central	1.071	4.010	5.645	0.409	0.955	6.869	1.457
Tacoma-North	0.128	3.561	3.406	0.007	0.029	4.558	5.749
Tamoshan	1.489	2.025	1.879	1.608	0.799	1.989	1.640
West Point	2.317	3.590	4.073	0.846	0.889	2.530	3.290
Avg. RMSE	**1.811**	**4.036**	**4.232**	**0.986**	**0.803**	**2.800**	**2.852**
3 Month WWTPs - Medium Template							
Fort Lewis	4.884*	0.603*	5.663	1.620	0.536	5.967	7.572
Miller	7.101	7.203	6.088	0.234	0.331	12.01	2.312
Salmon	2.551	7.203	12.410	0.234	0.331	2.354	2.448
Avg. RMSE	**4.845**	**5.003**	**8.054**	**0.696**	**0.399**	**6.777**	**4.110**
3 Month WWTPs - Small Template							
Bainbridge Kitsap	21.86	2.621	20.13	1.593	1.729	6.160	2.798
Harstene	3.712	1.839	6.051	1.764	1.338	5.139	2.506
Kitsap Kingston	6.254	2.350	4.054	1.534	2.011	3.566	2.506
Rustlewood	5.030	12.06	8.697	0.612	0.875	5.139	2.506
Seashore Villa	6.757	10.579	13.38	2.533	0.869	5.373	5.373
Suquamish	5.070	26.33	21.18	3.766	4.269	1.405	2.506
Vashon	9.323	2.702	6.896	1.457	0.905	2.713	2.506
Avg. RMSE	**8.287**	**8.356**	**11.484**	**1.894**	**1.714**	**4.214**	**2.957**
3 Month WWTPs - Other							
Carlyon	0.492	0.406	1.374	1.012	0.460	1.634	1.700
Simpson Kraft	0.063	0.040	0.085	0.182	0.290	3.868	--

*These values are based on plant-specific regressions developed using observed data sent by the specific WWTP or uploaded from DMR reports (not using the concentration templates or from regressions developed using data that Ecology collected at WWTPs).

Appendix F. River Nutrient Data

Table F-1 includes a summary of summer and annual DIN loads from all watersheds in South and Central Puget Sound.

Figures F-1 through F-7 present concentration box plots of various nutrients (nitrogen, phosphorus and carbon) for all rivers in the study area.

Table F-1. Mean summer (July-September) and annual DIN loads from all watersheds in South and Central Puget Sound for 2006-2007.

Watershed Name	Summer DIN Load (kg/d)	Annual DIN Load (kg/d)
South Puget Sound		
Anderson east	5.8	10
Anderson west	17	30
Artondale	12	38
Burley Cr	38	51
Butler Cr	0.9	6.7
Campbell Cr	2.0	7.6
Chambers Cr	118	389
Coulter Cr	2.1	11
Cranberry Cr	11	42
Dana Passage	6.9	19
Deer Cr	2.6	15
Deschutes R	248	993
Dutcher Cove	2.5	6.2
Ellis_Mission Cr	3.7	10
Filucy Bay	4.6	15
Frye Cove	2.2	6.4
Gallagher Cove	2.5	17
Glen Cove	4.6	15
Goldsborough Cr	8.3	80
Goodnough Cr	4.9	16
Grant	1.3	5.0
Green Cove	2.7	21
Gull Harbor	5.3	14
Hale Passage	6.7	22
Henderson Inlet	5.4	13
Herron	2.0	4.9
Jarrel Cove	2.8	11
Johns Cr	4.2	17

Watershed Name	Summer DIN Load (kg/d)	Annual DIN Load (kg/d)
South Puget Sound		
Kennedy_Schneider	16.0	110
Ketron	3	9
Mayo Cove	2	8
McAllister Cr	110	295
McLane Cr	5.3	39.5
McNeil Isl	20.0	34.0
Mill Cr	22	125
Minter Cr	15.2	50
Moxlie Cr	8	23
Nisqually R	394.2	1748
Peale Passage	1.8	7
Perry Cr	6	18
Purdy Cr	4.6	14.8
Rocky Cr	13.2	33
Rosedale	7.7	25
Schneider Cr	0.3	2.0
Sequalitchew Cr	63.8	210
Sherwood Cr	11.6	45
Skookum Cr	15.0	86
Snodgrass Cr	0.9	6
Sun Pt	0.9	3.5
Tolmie	15.3	38
Van Gelden	6.1	20
Vaughn	3.1	8
Whitman Cove	3.7	9
Wilson Pt	1.5	5.5
Woodard Cr	14.6	40
Woodland Cr	74.0	183

Watershed Name	Summer DIN Load (kg/d)	Annual DIN Load (kg/d)
Central Puget Sound		
Buenna	4.9	16
Curley Cr	23	75
Des Moines Cr	9.2	30
Ellisport	3.9	13
Federal Way	6.7	22
Gig Harbor	15	48
Green R	368	1942
Hylebos Cr	39	130
Judd Cr	7.0	23
Lake Washington	26	580
Magnolia Bch	6.3	21
Miller Cr	25	81
Olalla Cr	18	58
Puyallup R	762	2420
Saltwater St Pk	3.9	13
Shingle Mill Cr	6.1	20
Sinclair Dyes	50	280
Tahlequah	4.6	15
University Place	7.8	26

	Summer DIN Load (kg/d)	Annual DIN Load (kg/d)
South Puget Sound Subtotal	1370	5080
Central Puget Sound Total	1387	5814
TOTAL	2757	10894

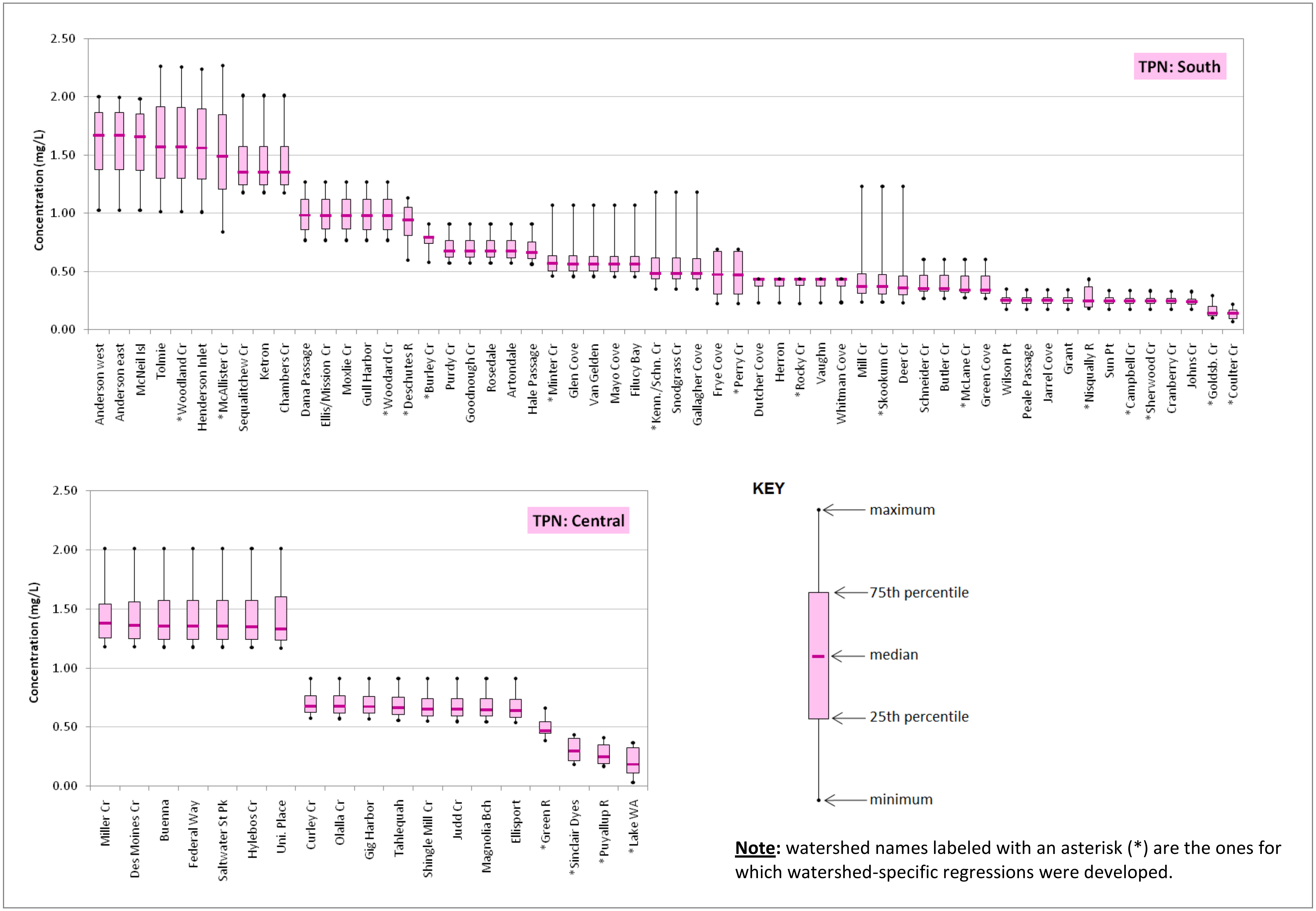


Figure F-1. Box plots of total persulfate nitrogen concentrations for 2006 – 2007 for watersheds in South (top) and Central (bottom) Puget Sound

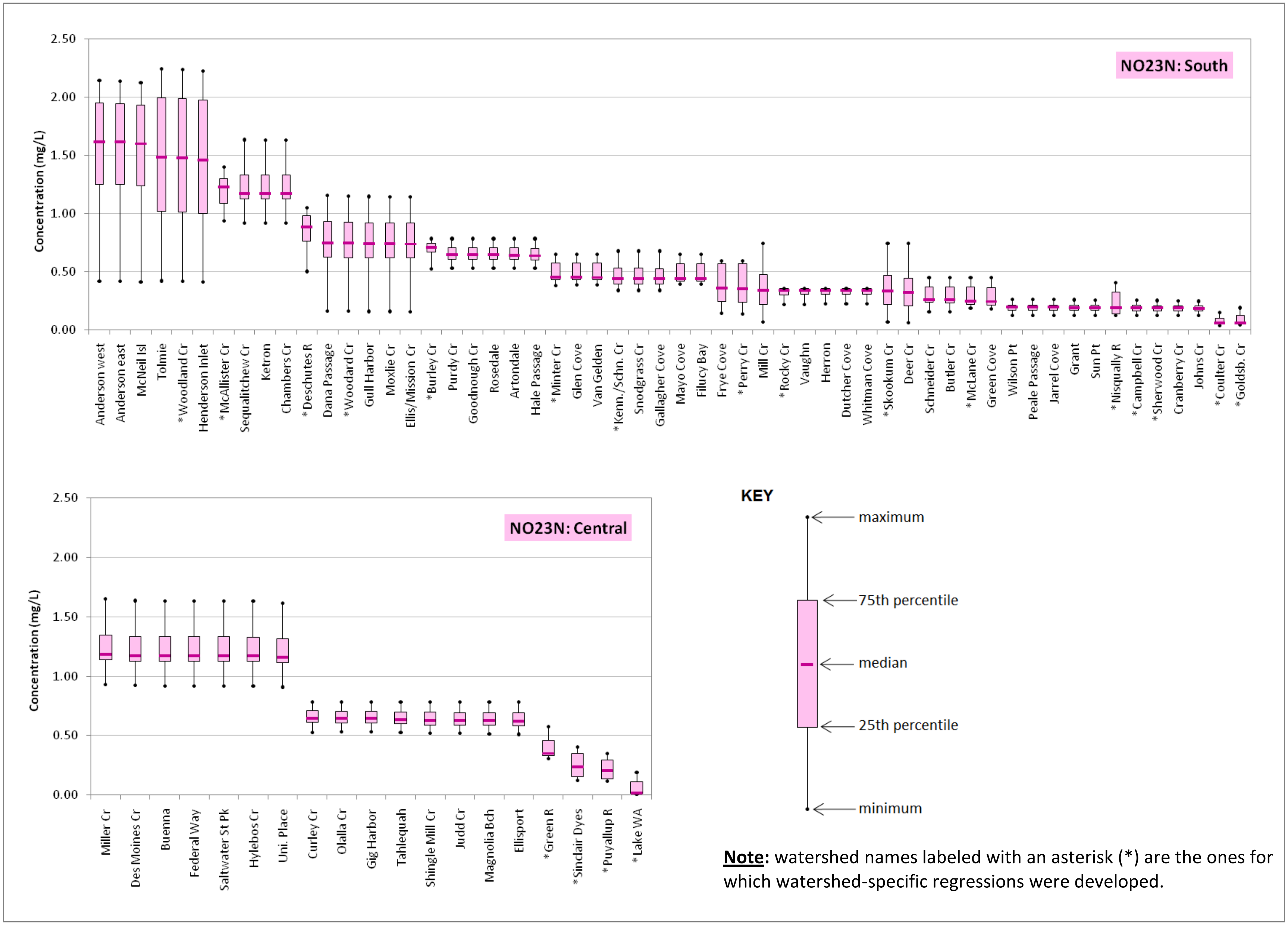


Figure F-2. Box plots of nitrate + nitrite concentrations for 2006 – 2007 for watersheds in South (top) and Central (bottom) Puget Sound

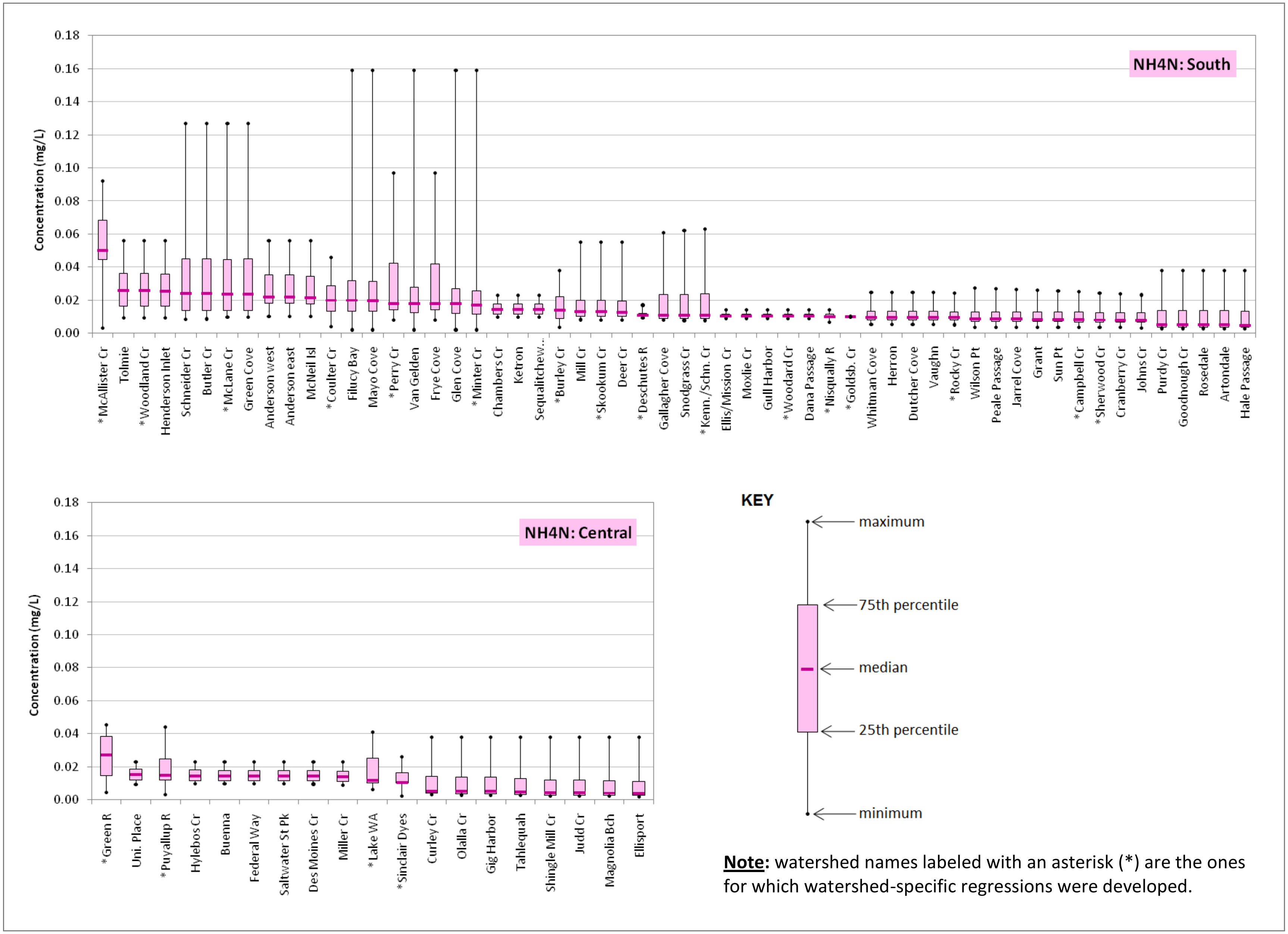


Figure F-3. Box plots of ammonium concentrations for 2006 – 2007 for watersheds in South (top) and Central (bottom) Puget Sound

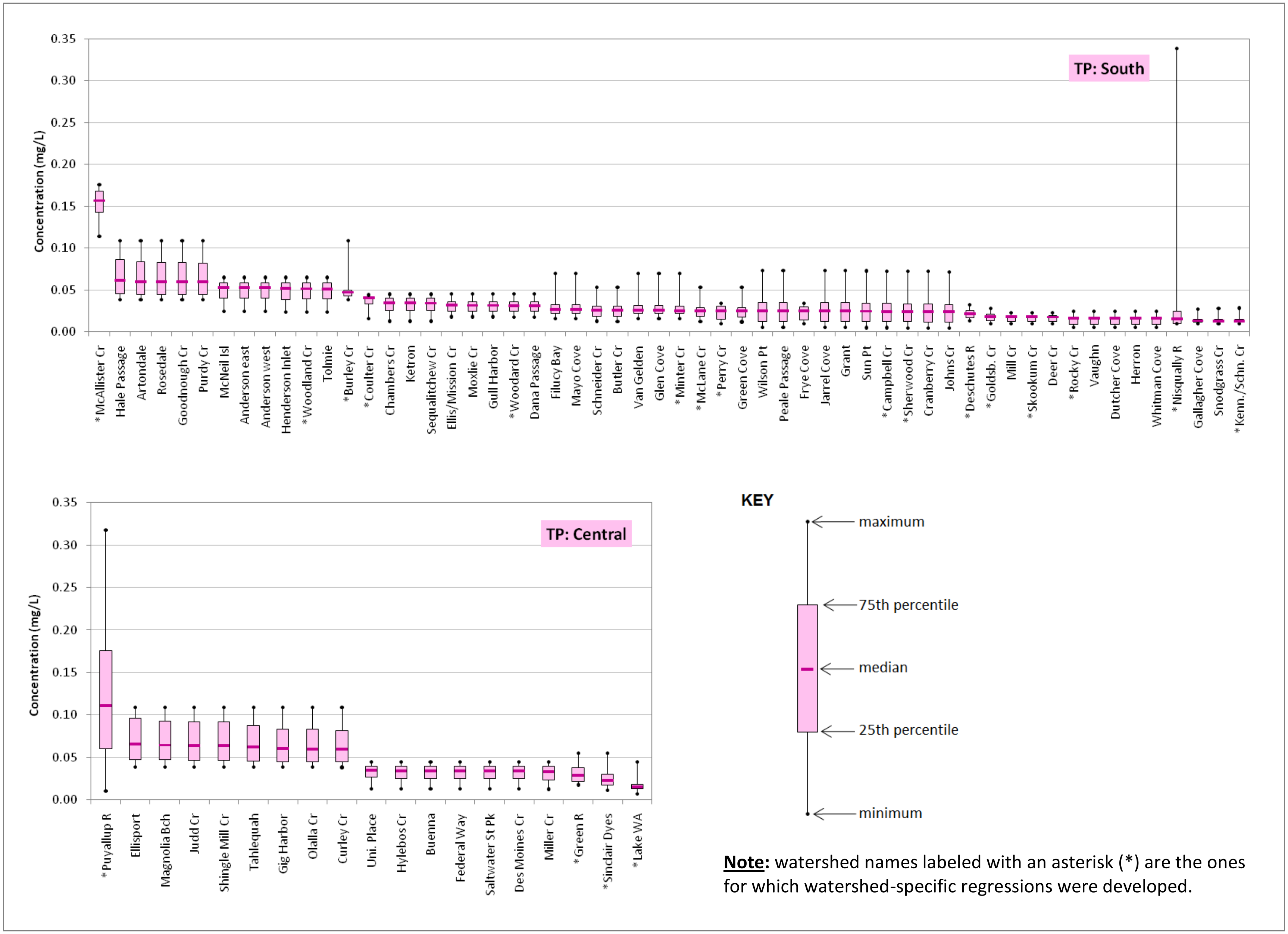


Figure F-4. Box plots of total phosphorus concentrations for 2006 – 2007 for watersheds in South (top) and Central (bottom) Puget Sound

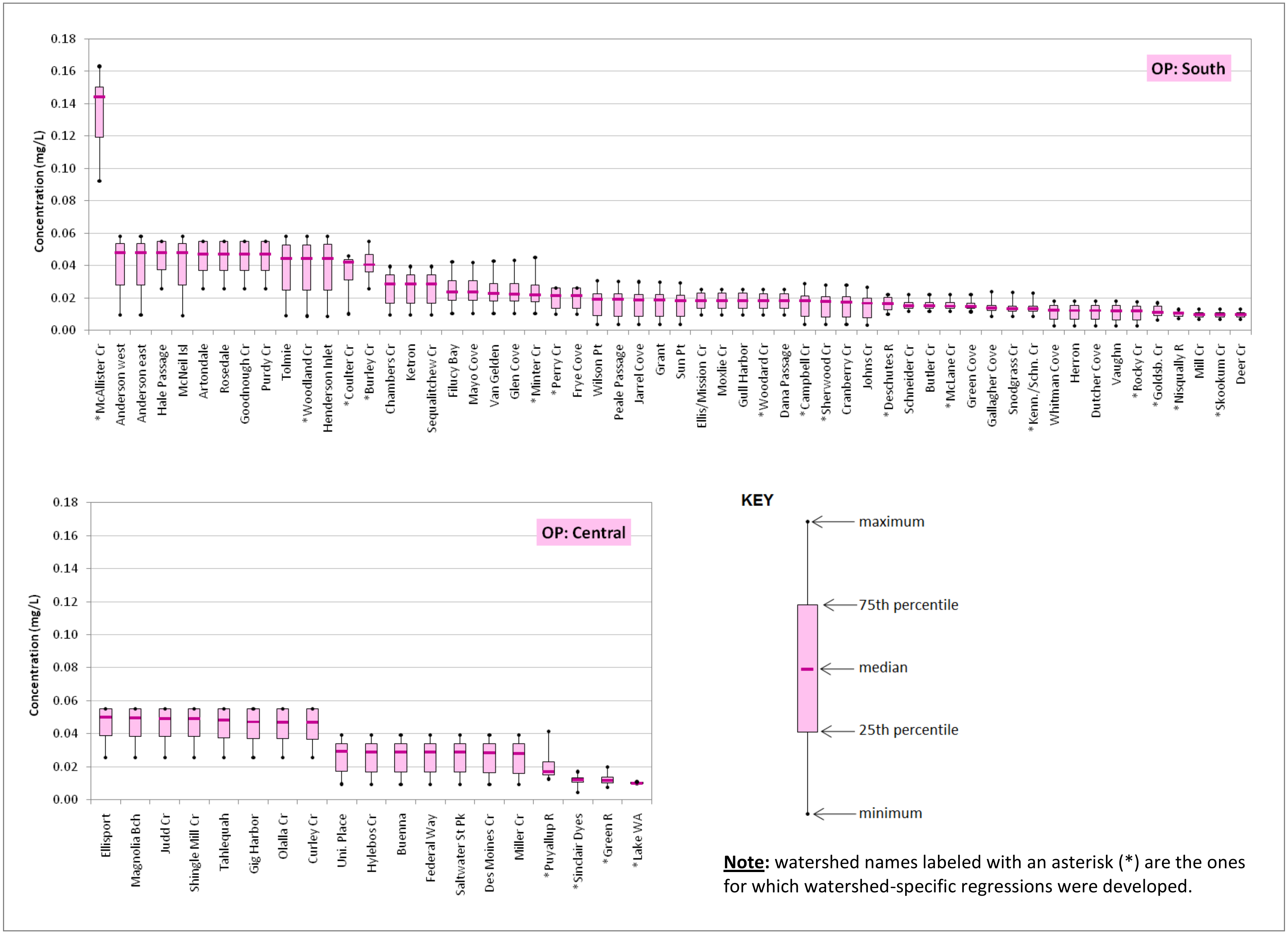


Figure F-5. Box plots of ortho-phosphate concentrations for 2006 – 2007 for watersheds in South (top) and Central (bottom) Puget Sound

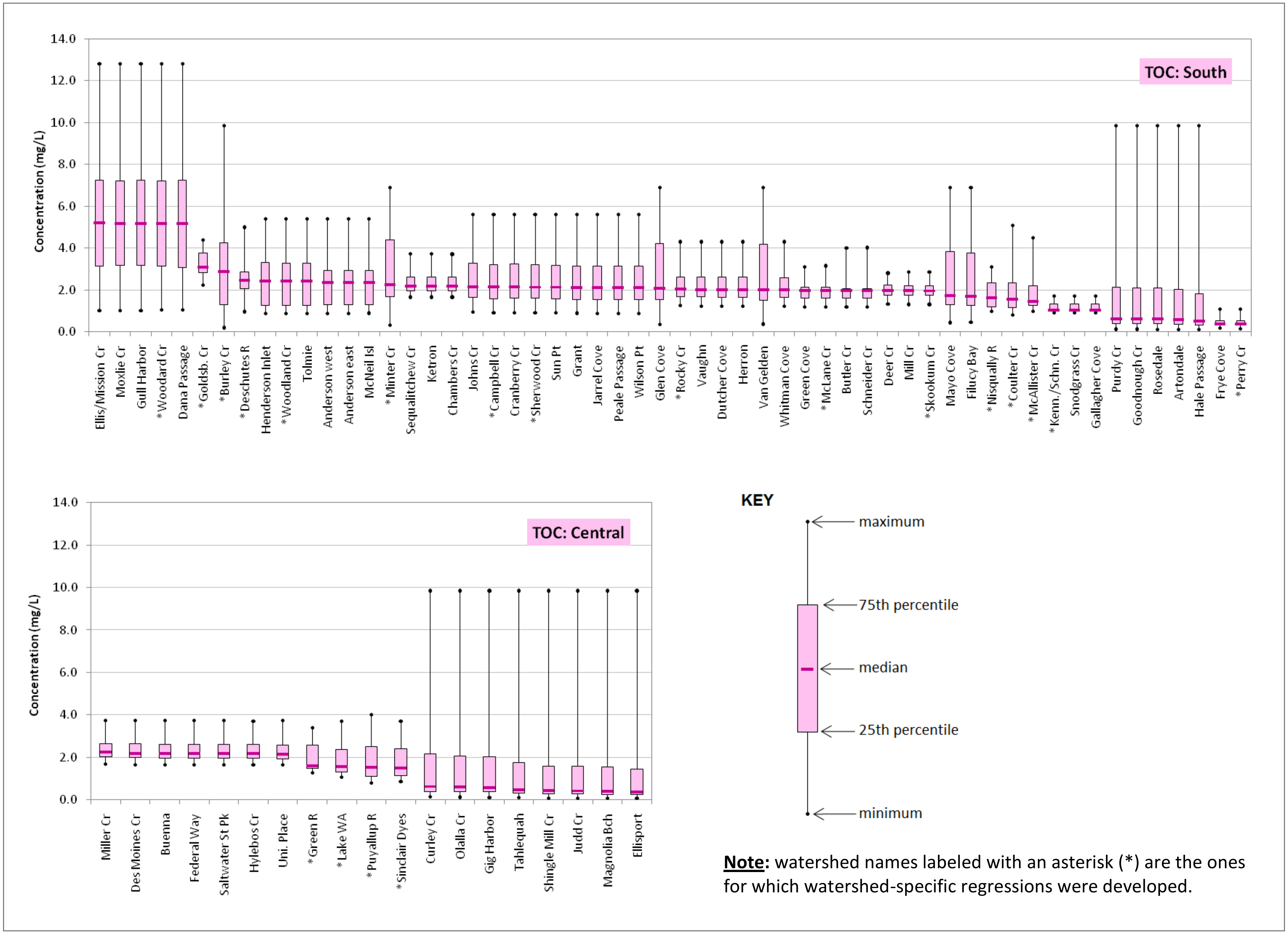
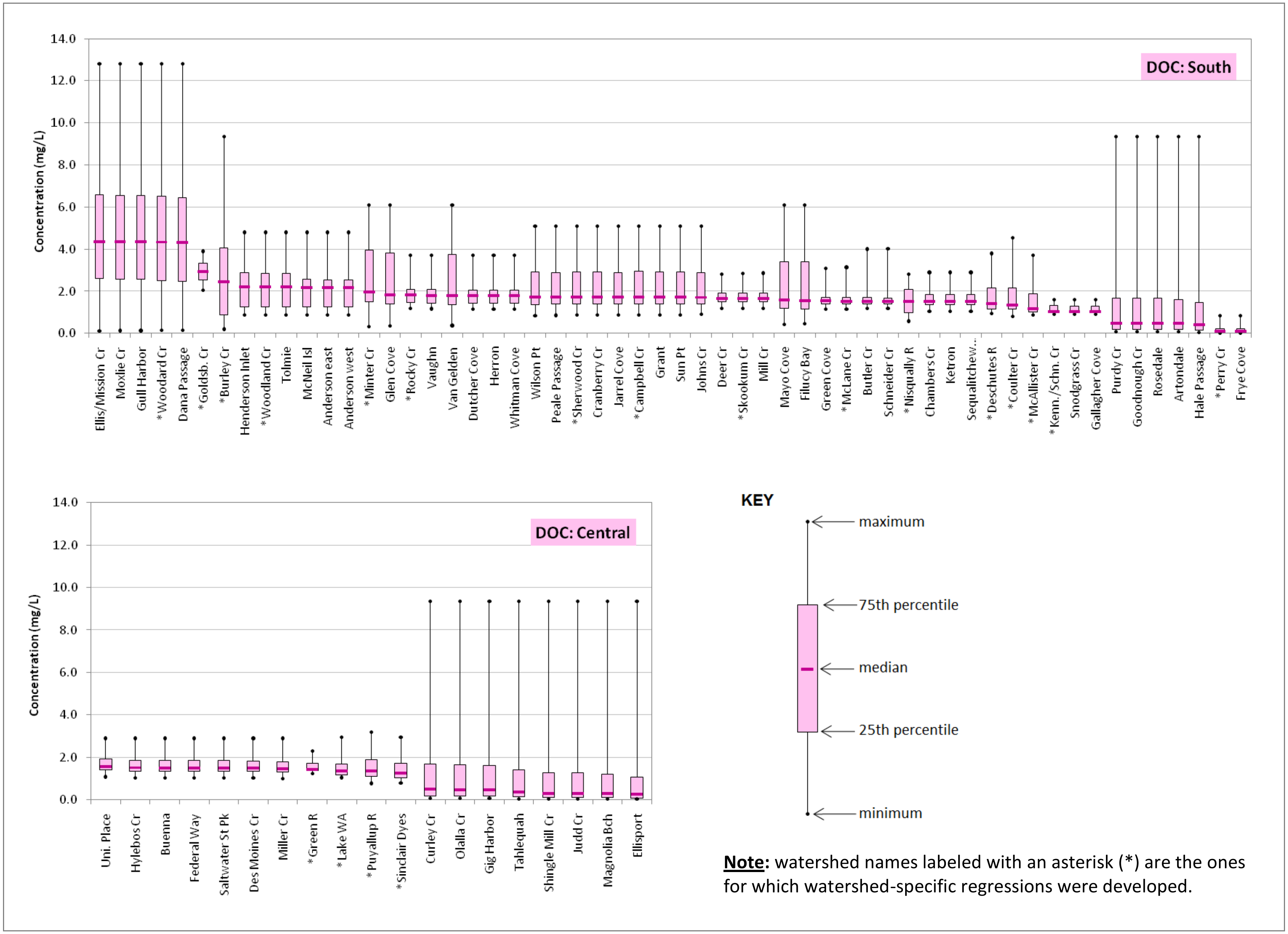


Figure F-6. Box plots of total organic carbon concentrations for 2006 – 2007 for watersheds in South (top) and Central (bottom) Puget Sound



Note: watershed names labeled with an asterisk (*) are the ones for which watershed-specific regressions were developed.

Figure F-7. Box plots of dissolved organic carbon concentrations for 2006 – 2007 for watersheds in South (top) and Central (bottom) Puget Sound

Figures F-8 through F-14 present dot plots of nutrient loads for various parameters from all rivers in the study area.

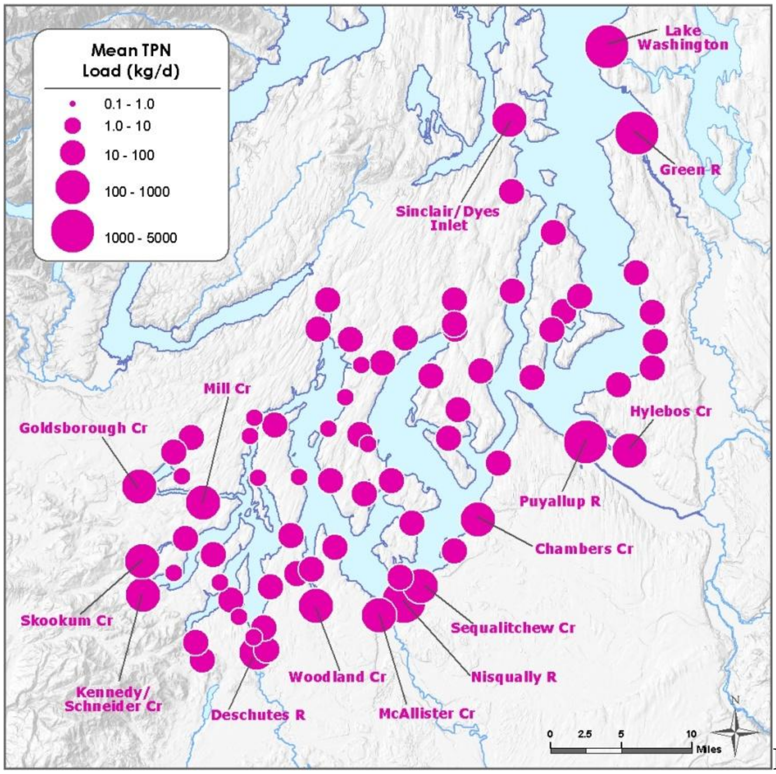


Figure F-8. Mean total persulfate nitrogen loads from watersheds during 2006-2007.

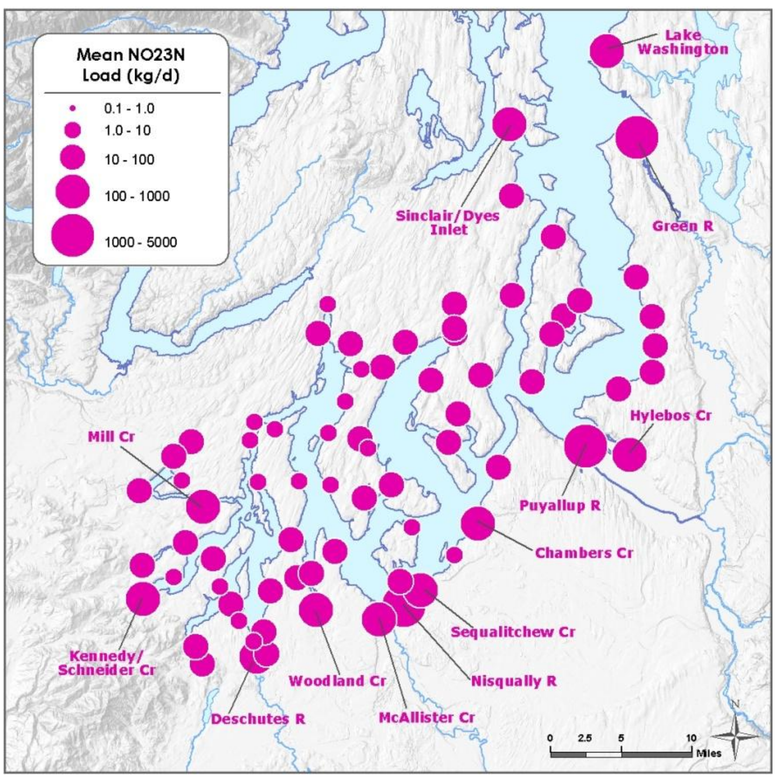


Figure F-9. Mean nitrate + nitrite loads from watersheds during 2006-2007.

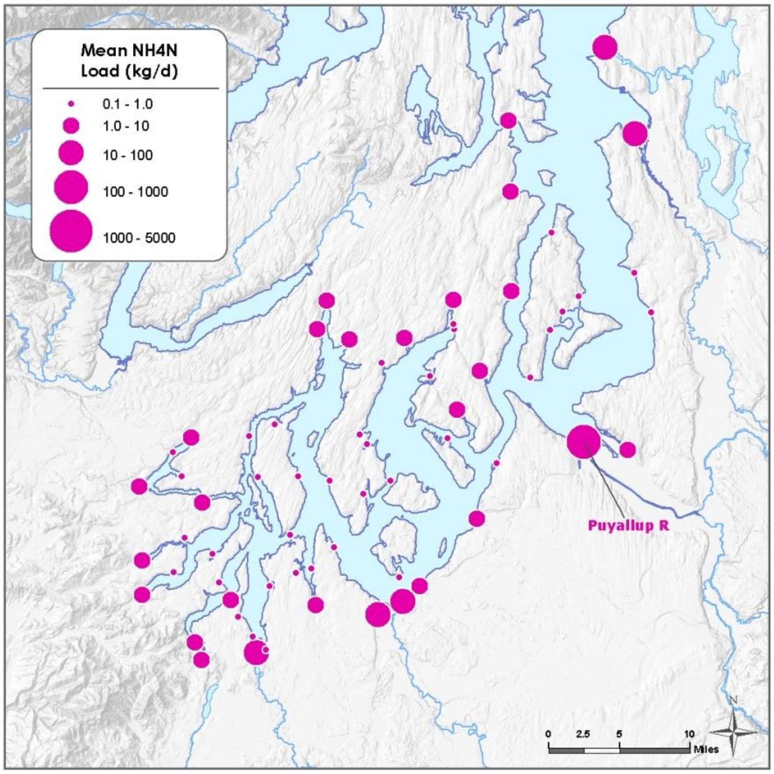


Figure F-10. Mean ammonium loads from watersheds during 2006-2007.

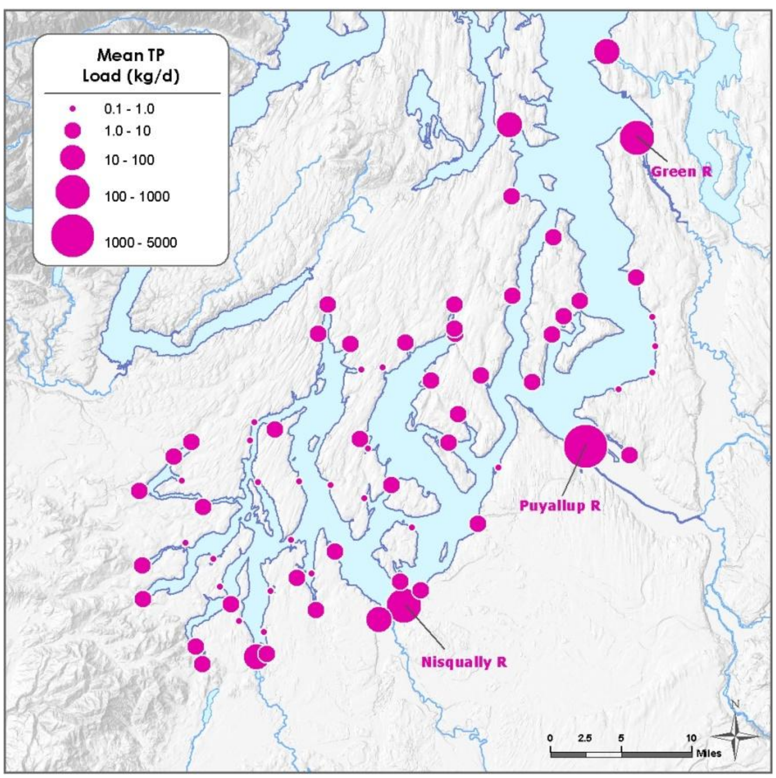


Figure F-11. Mean total phosphorus loads from watersheds during 2006-2007.

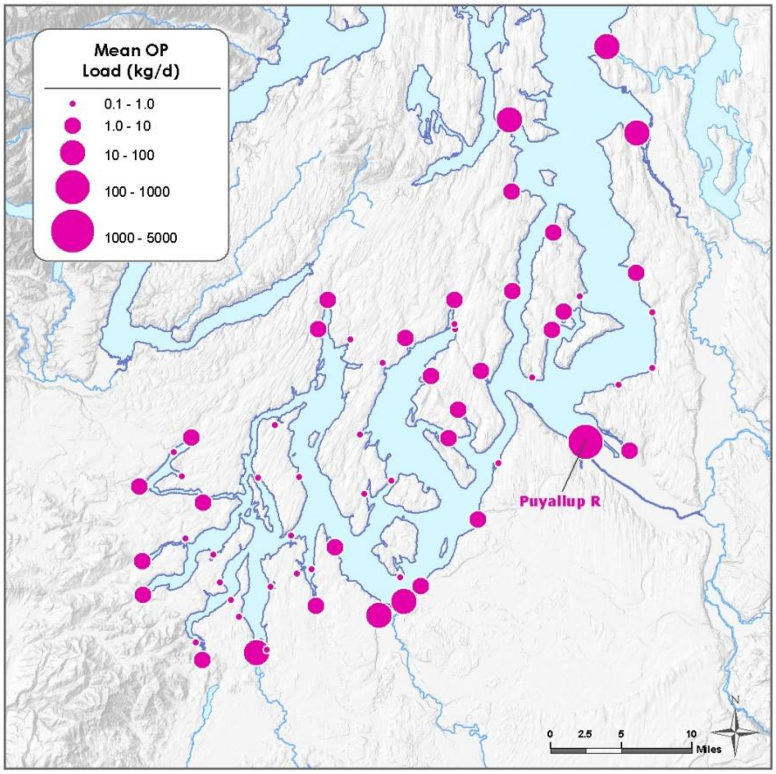


Figure F-12. Mean ortho-phosphate loads from watersheds during 2006-2007.

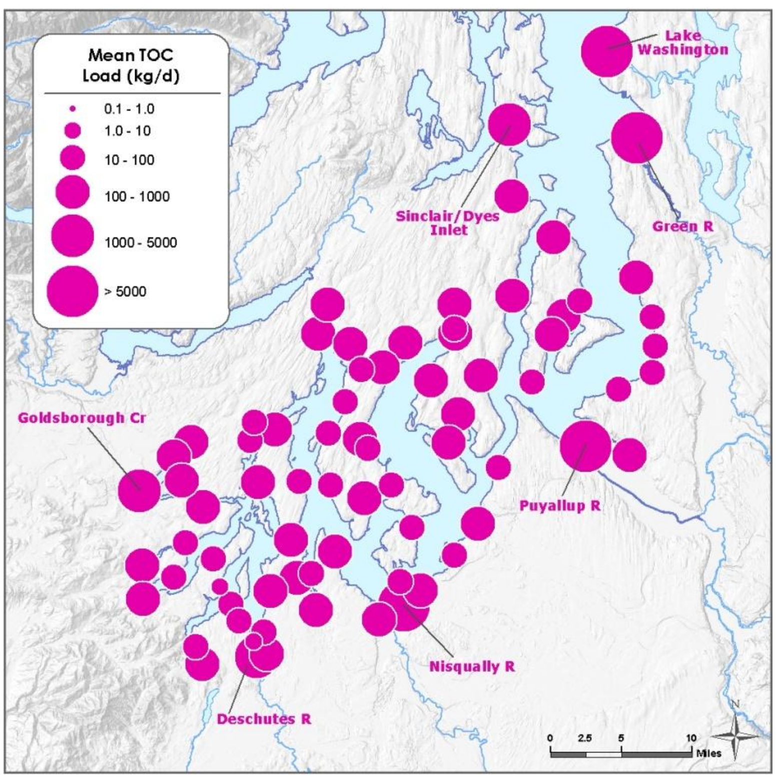


Figure F-13. Mean total organic carbon loads from watersheds during 2006-2007.

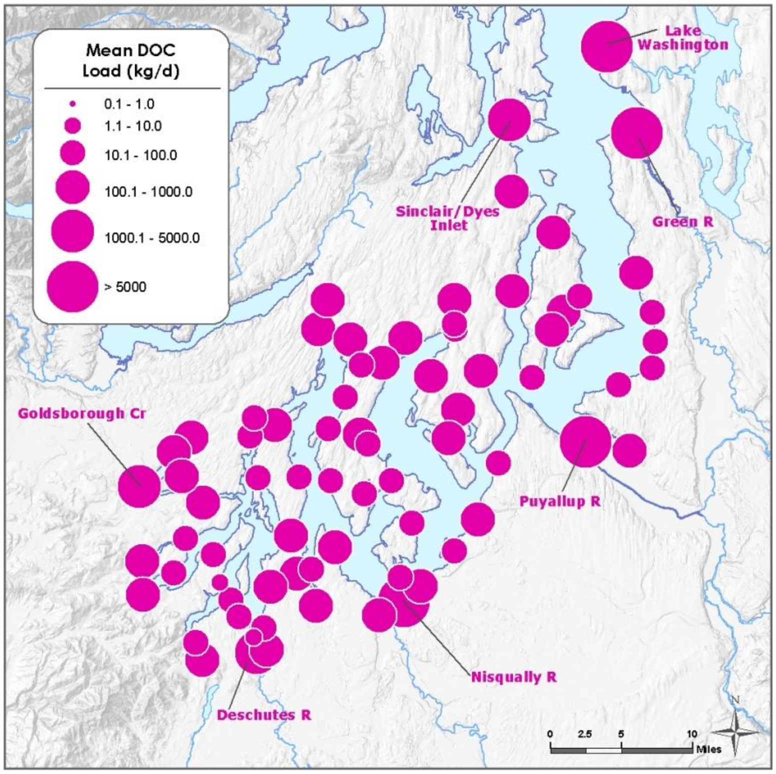


Figure F-14. Mean dissolved organic carbon loads from watersheds during 2006-2007.

Figures F-15 through F-17 present mean monthly nitrogen, phosphorus, and organic carbon loads totaled by the different regions in South and Central Puget Sound into which they drain.

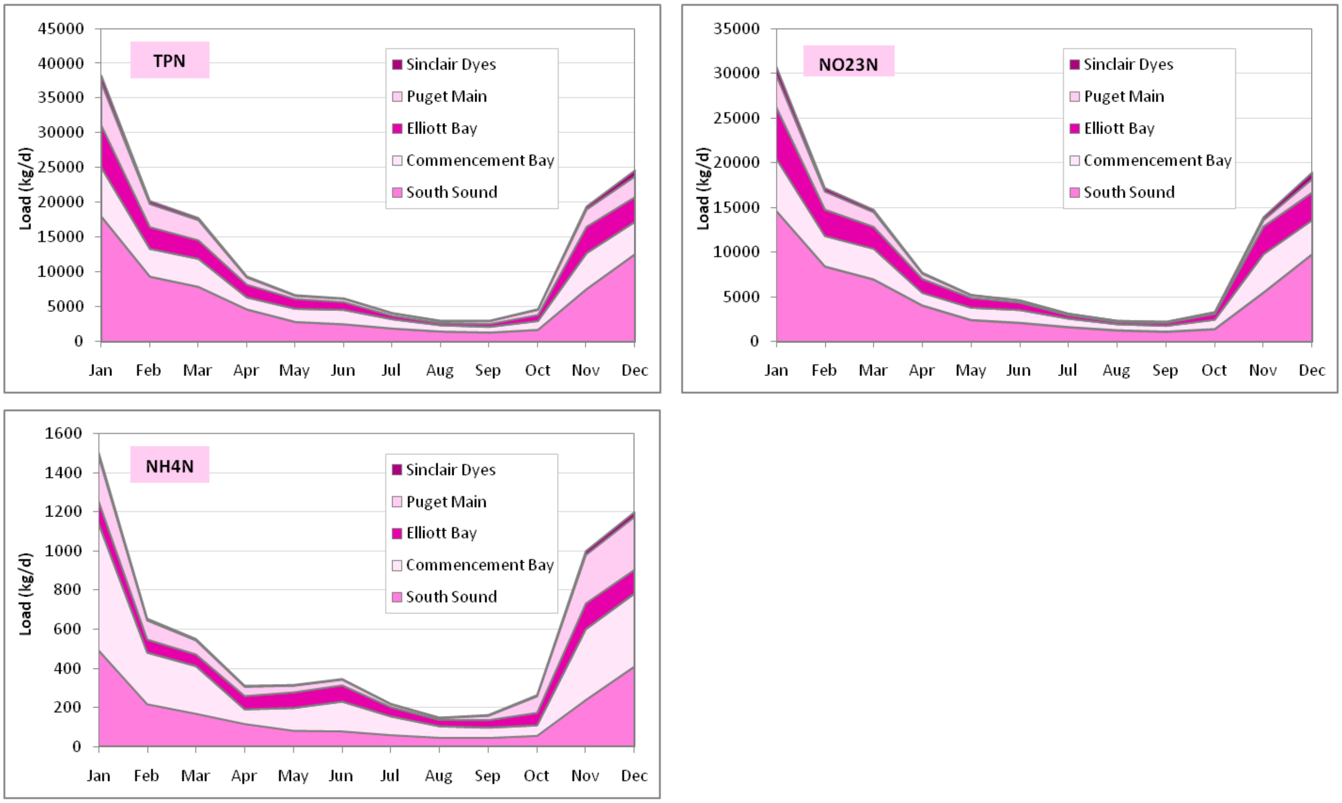


Figure F-15. Mean 2006-2007 monthly nitrogen loads from watersheds totaled according to the regions in South and Central Puget Sound into which they drain.

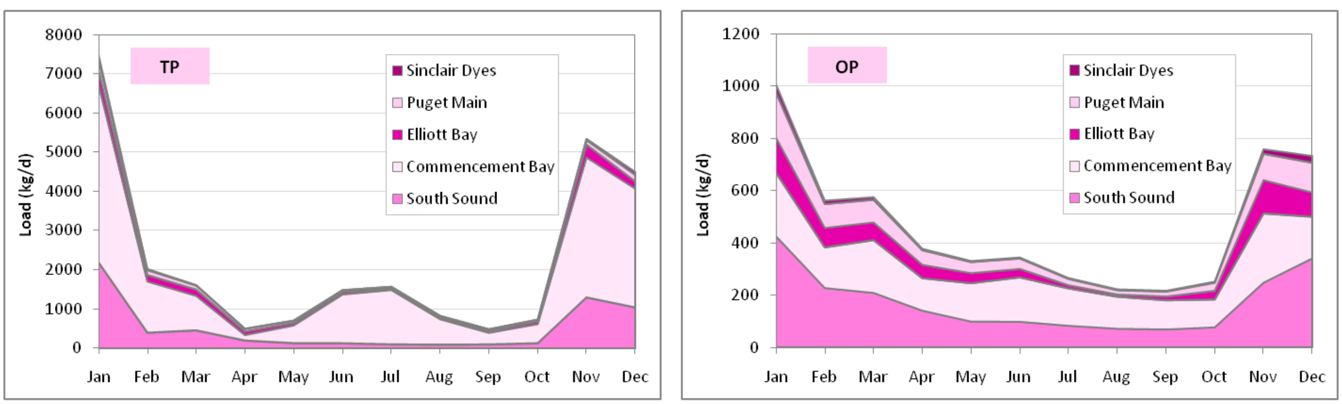


Figure F-16. Mean 2006-2007 monthly phosphorus loads from watersheds totaled according to the regions in South and Central Puget Sound into which they drain.

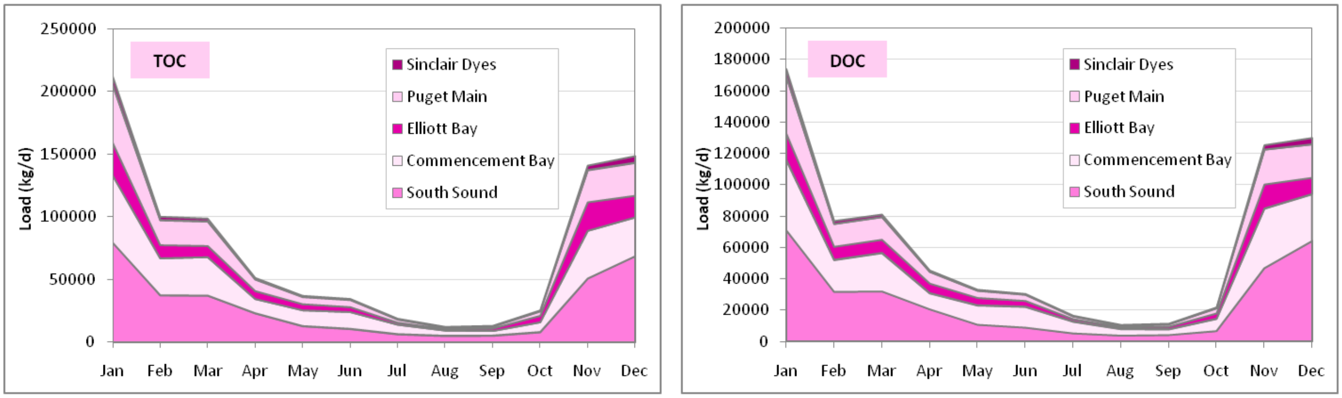


Figure F-17. Mean 2006-2007 monthly organic carbon loads from watersheds totaled according to the regions in South and Central Puget Sound into which they drain.

Appendix G. WWTP Nutrient Data

Table G-1 includes a summary of summer and annual DIN loads from all WWTPs in South and Central Puget Sound.

Table G-1. Mean summer (July-September) and annual DIN loads from all WWTPs in South and Central Puget Sound for 2006-2007.

Watershed Name	Summer DIN Load (kg/d)	Annual DIN Load (kg/d)
Boston Harbor	1.3	2.5
Carlyon	4.2	4.2
Chambers Creek	1984	2056
Fort Lewis	344	329
Hartstene Pointe	1.0	2.5
LOTT	62	159
McNeil Is	6.2	7.7
Rustlewood	0.4	1.0
Seashore Villa	0.3	0.4
Shelton	19	57
Tamoshan	0.8	0.8
Taylor Bay	0.3	0.3
Bainbridge Is (City)	14	19
Bainbridge Kitsap Co 7	2.1	3.0
Bremerton	175	361
Central Kitsap	435	453
Gig Harbor	29	38
Kitsap Co Kingston	3.0	3.8
Lakota	745	797
Manchester	4.9	6.8
Midway	390	422
Miller Creek	308	336
Port Orchard	149	131
Redondo	189	238
Salmon Creek	214	284
Simpson Kraft	13	15
South King	7576	8814
Suquamish	4.6	7.2
Tacoma Central	1984	2056
Tacoma North	359	388
US Oil & Refining	0.4	0.6
Vashon	2.4	5.1
West Point	9401	9669

	Summer DIN Load (kg/d)	Annual DIN Load (kg/d)
South Puget Sound Subtotal	2423	2619
Central Puget Sound Total	21999	24047
TOTAL	24906	27326

Figures G-1 through G-8 present concentration box plots of various nutrients (nitrogen, phosphorus, carbon, and Biochemical oxygen demand) for all WWTPs in the study area.

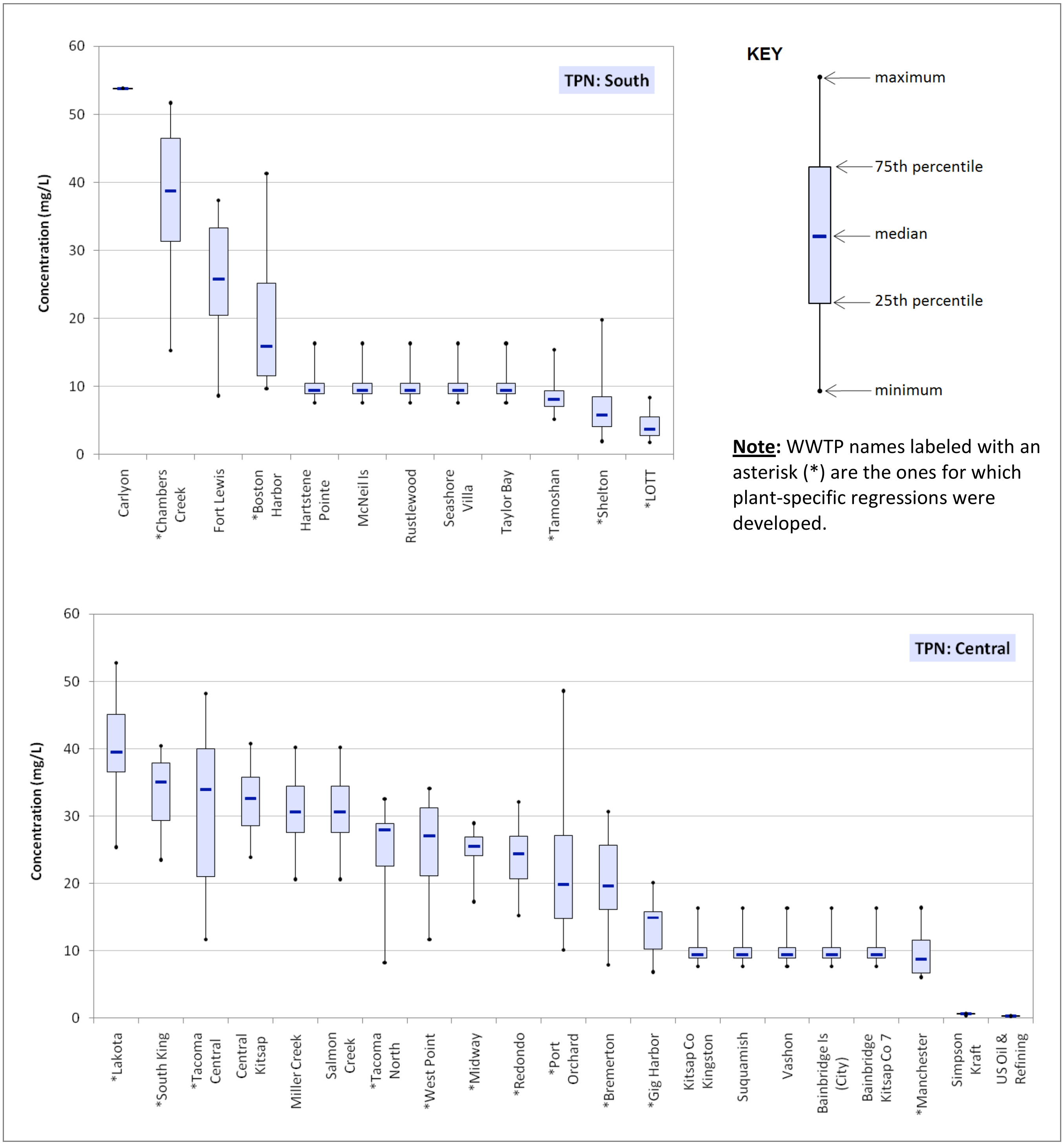


Figure G-1. Box plots of total persulfate nitrogen concentrations for 2006 – 2007 for WWTPs in South (top) and Central (bottom) Puget Sound

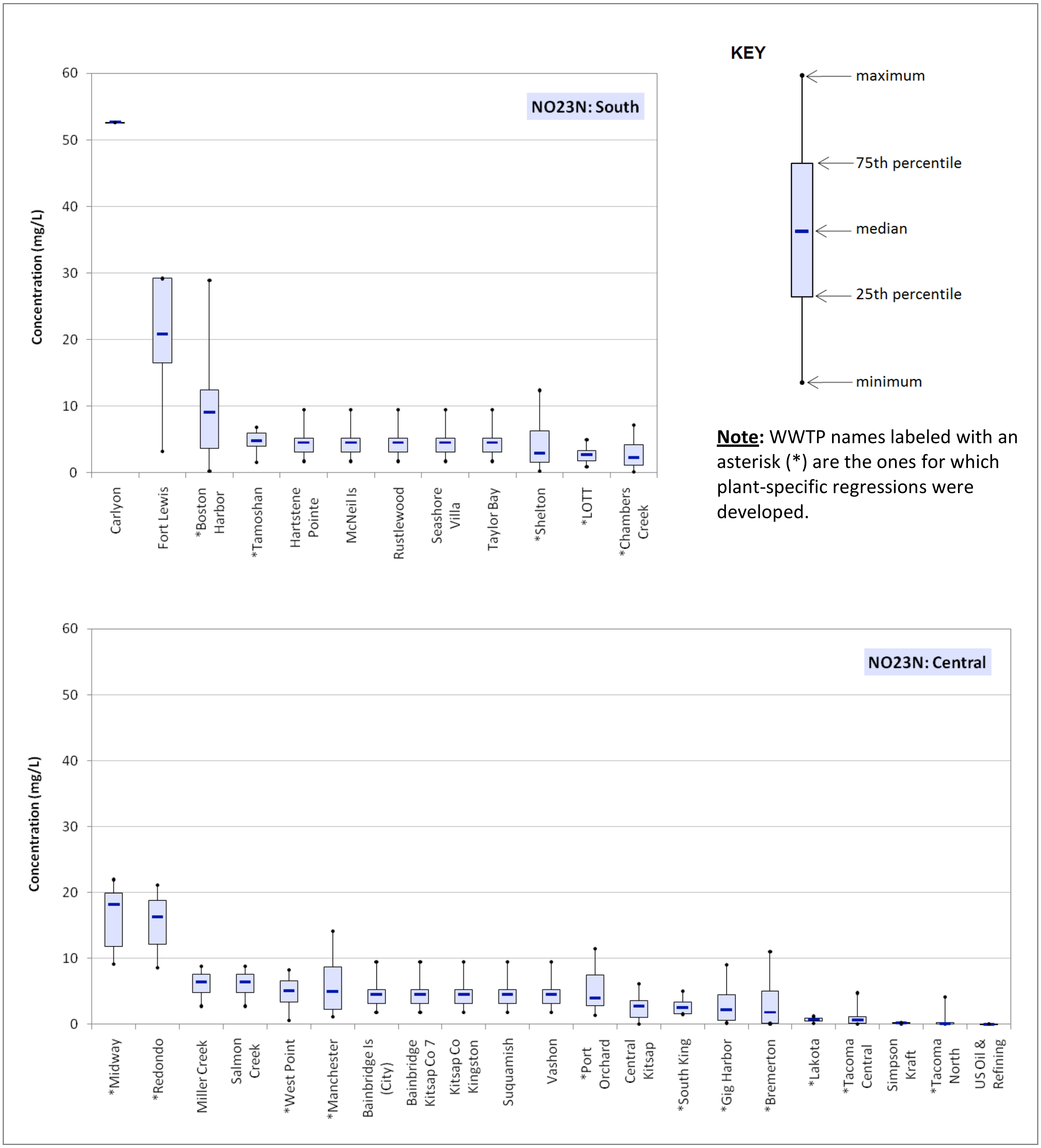


Figure G-2. Box plots of nitrate + nitrite concentrations for 2006 – 2007 for WWTPs in South (top) and Central (bottom) Puget Sound

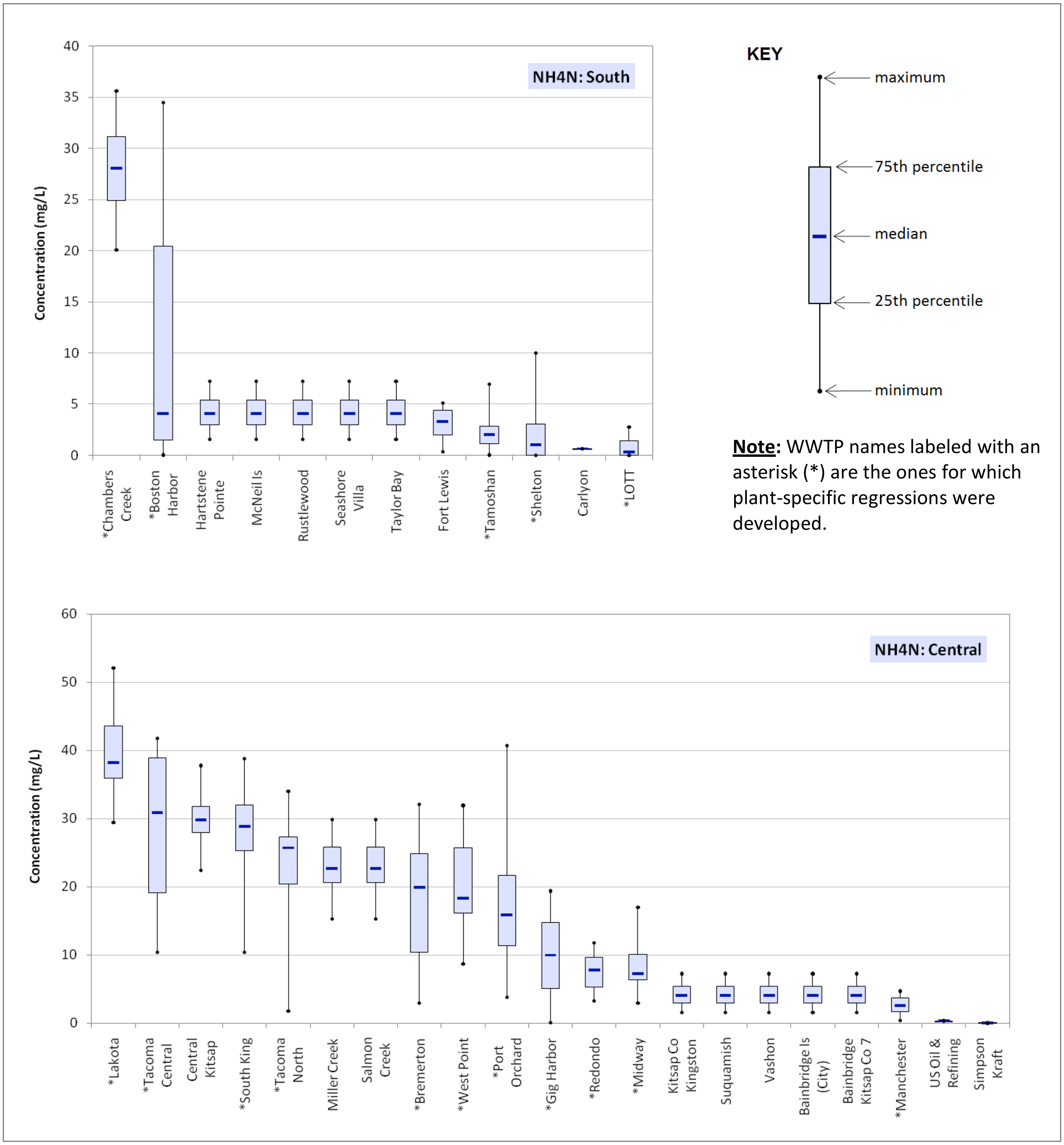


Figure G-3. Box plots of ammonium concentrations for 2006 – 2007 for WWTPs in South (top) and Central (bottom) Puget Sound

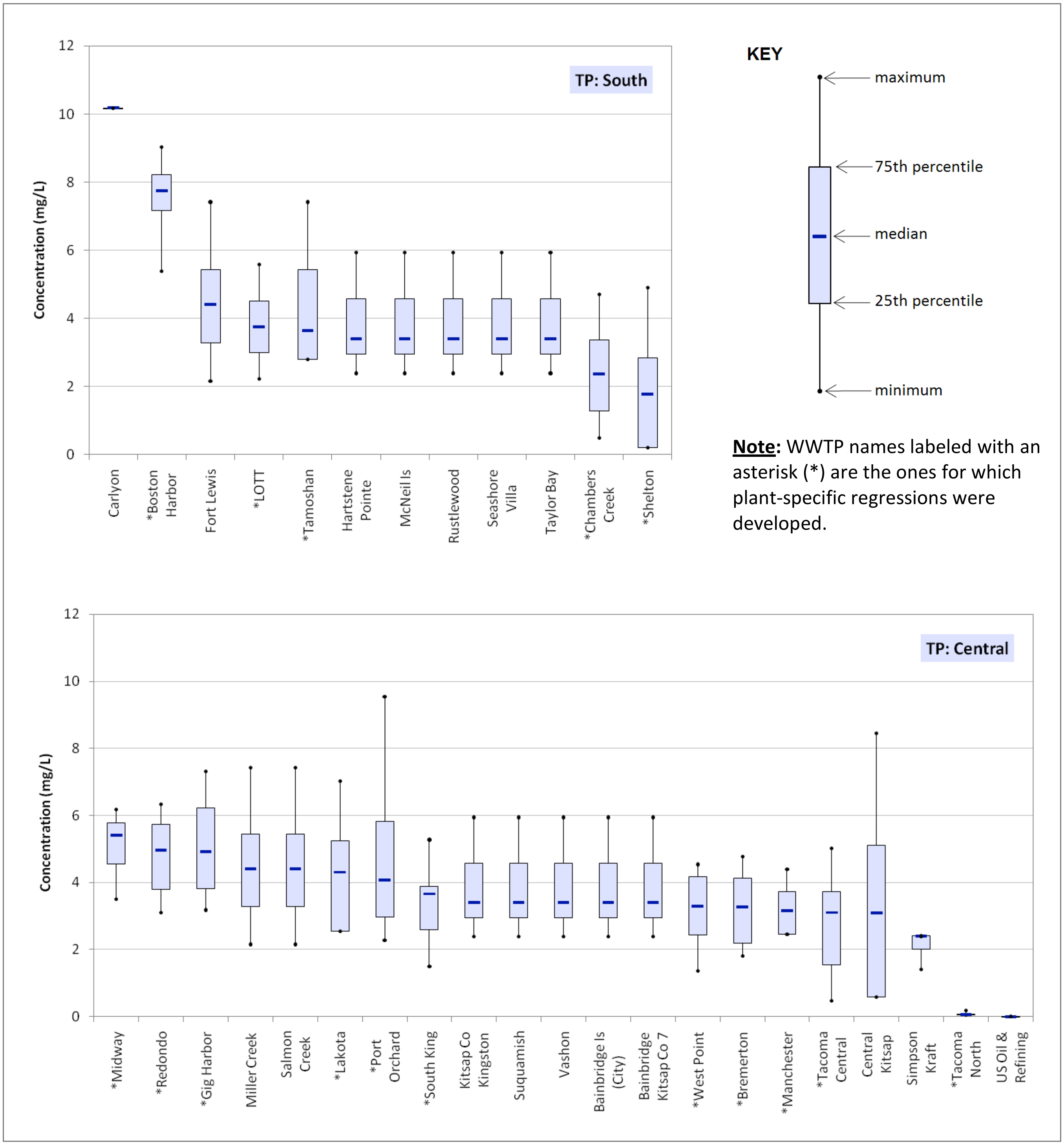


Figure G-4. Box plots of total phosphorus concentrations for 2006 – 2007 for WWTPs in South (top) and Central (bottom) Puget Sound

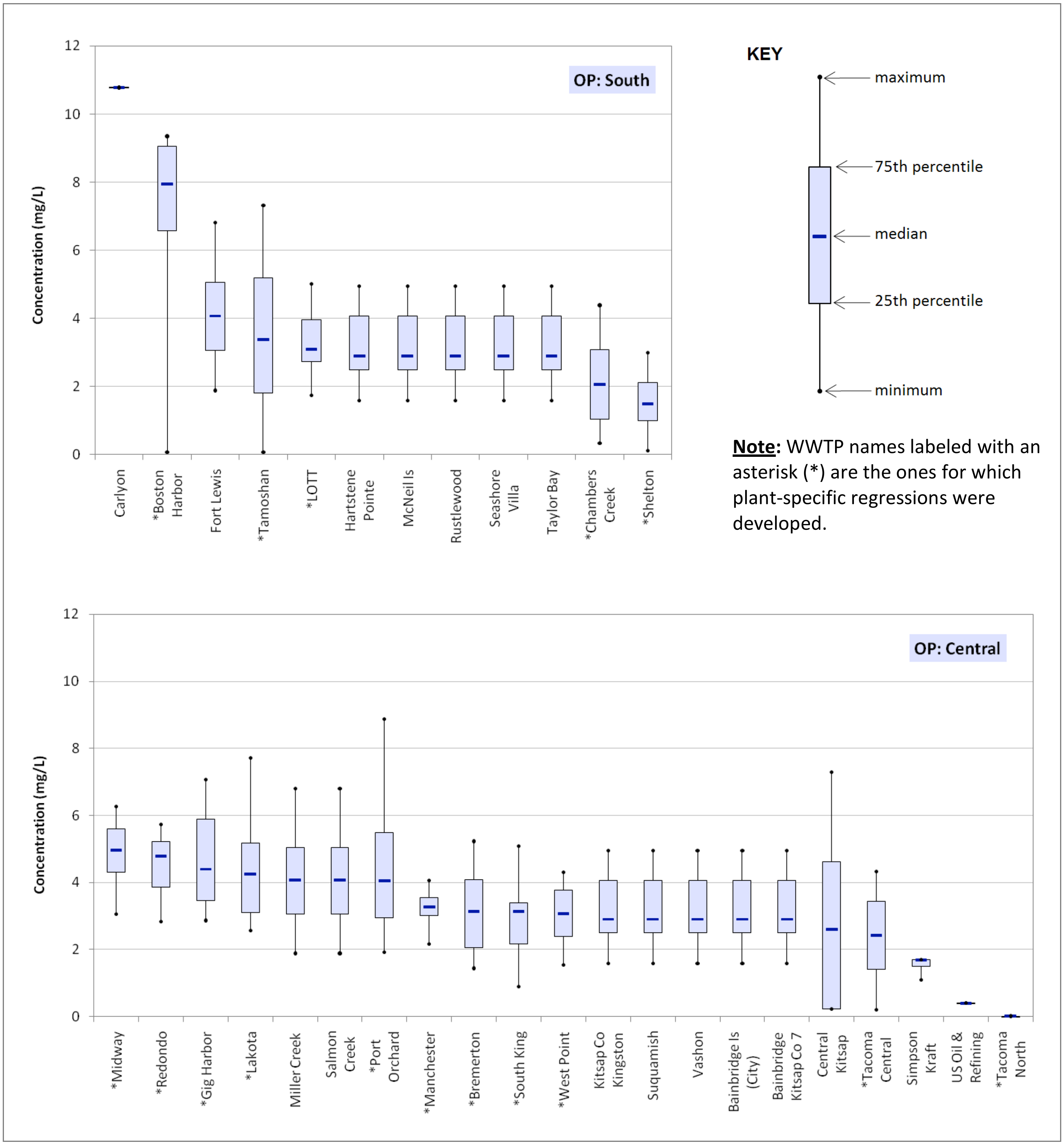


Figure G-5. Box plots of ortho-phosphate concentrations for 2006 – 2007 for WWTPs in South (top) and Central (bottom) Puget Sound

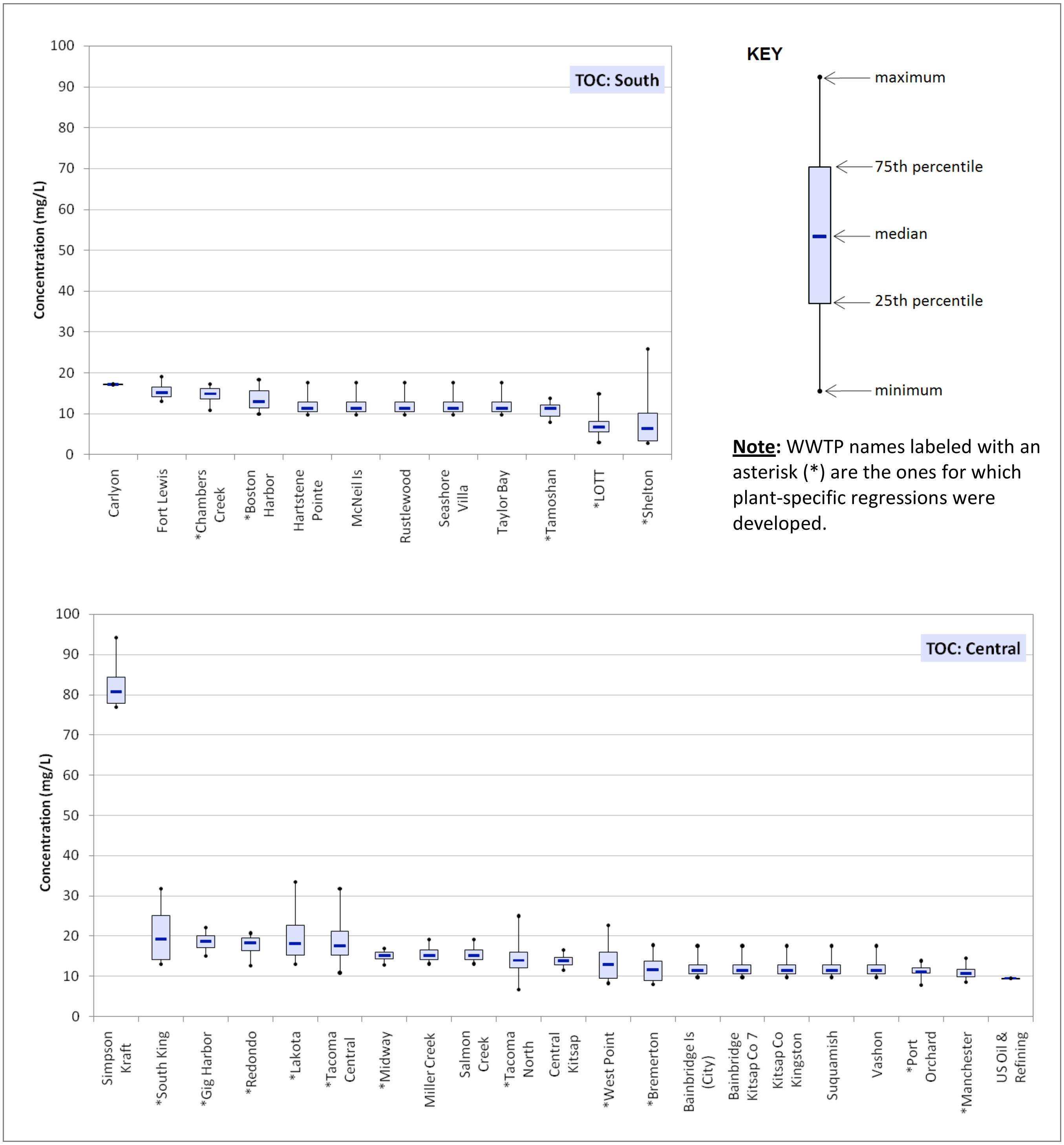


Figure G-6. Box plots of total organic carbon concentrations for 2006 – 2007 for WWTPs in South (top) and Central (bottom) Puget Sound

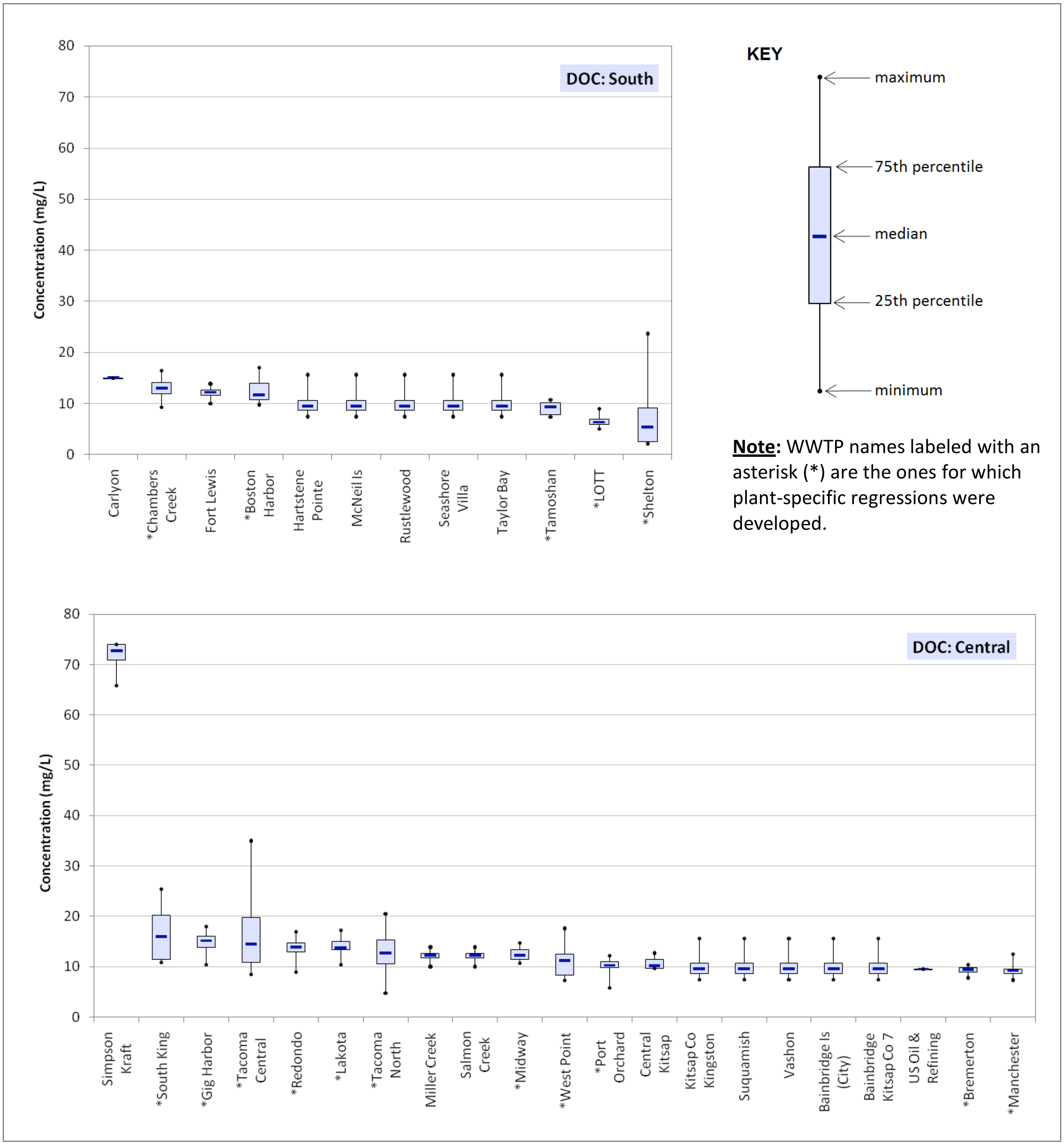


Figure G-7. Box plots of dissolved organic carbon concentrations for 2006 – 2007 for WWTPs in South (top) and Central (bottom) Puget Sound

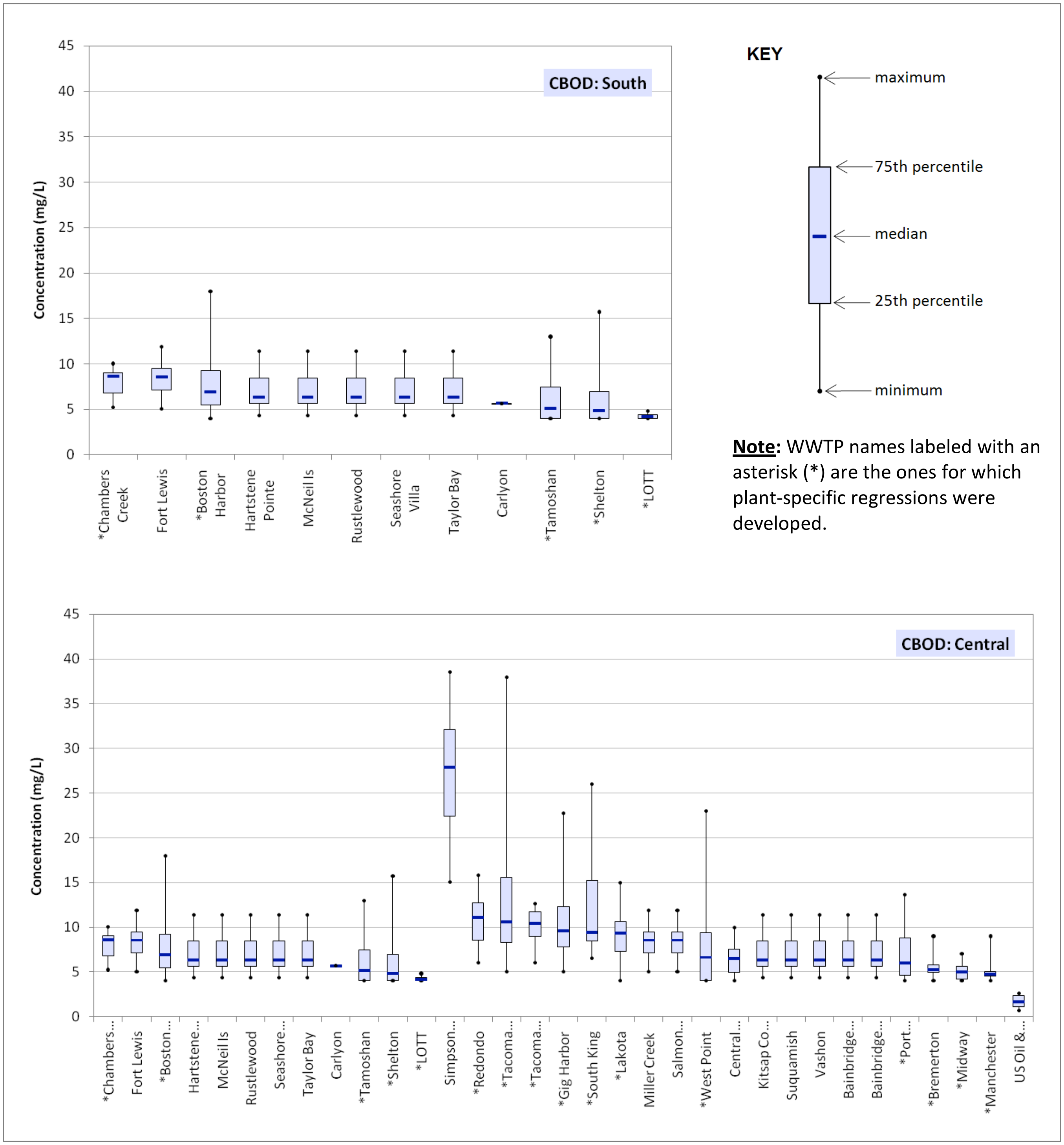


Figure G-8. Box plots of carbonaceous biochemical oxygen demand concentrations for 2006 – 2007 for WWTPs in South (top) and Central (bottom) Puget Sound

Figures G-9 through G-16 present dot plots of nutrient loads for various parameters from all WWTPs in the study area.

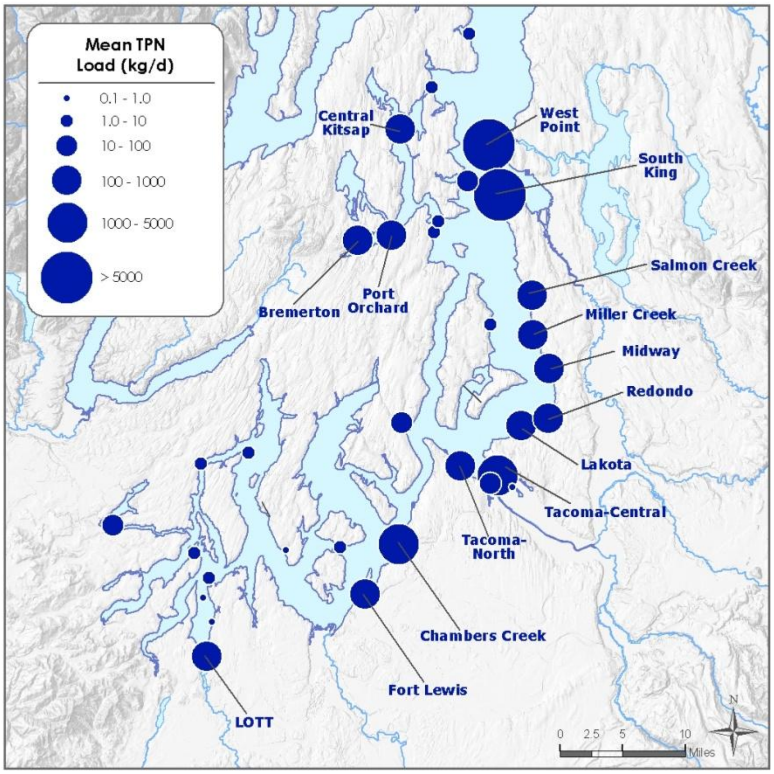


Figure G-9. Mean total persulfate nitrogen loads from WWTPs during 2006-2007.

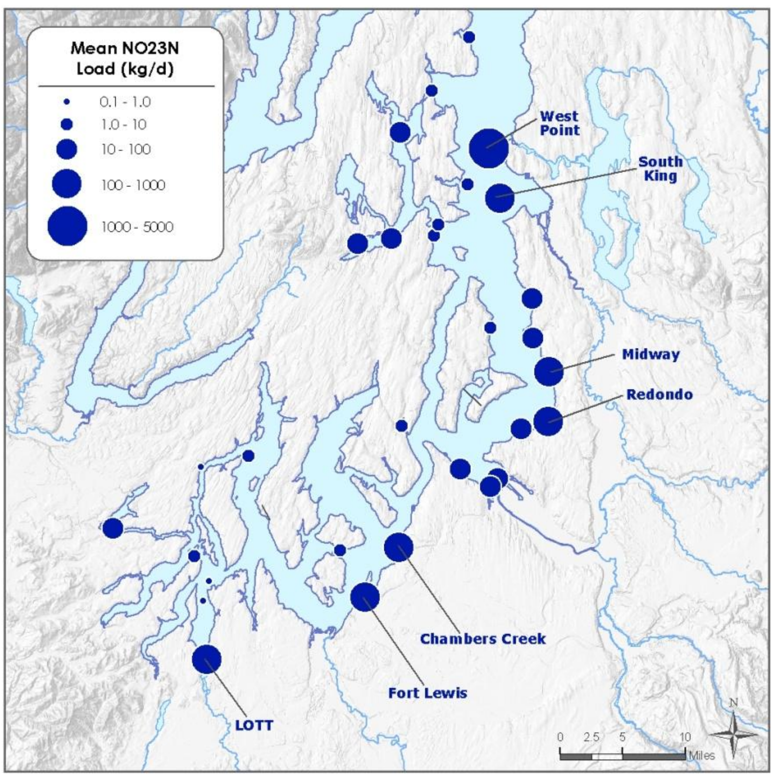


Figure G-10. Mean nitrate + nitrite loads from WWTPs during 2006-2007.

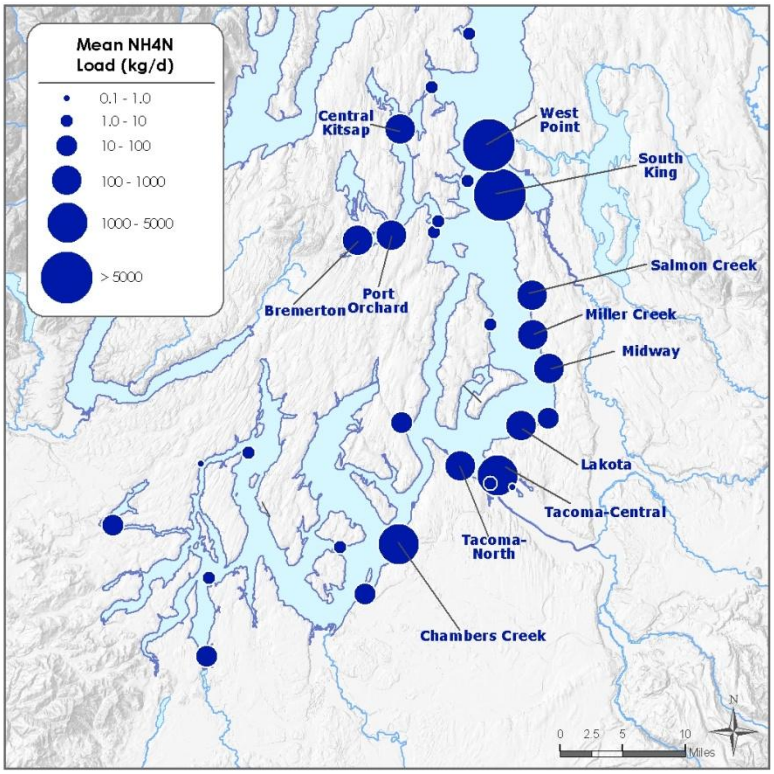


Figure G-11. Mean ammonium loads from WWTPs during 2006-2007.

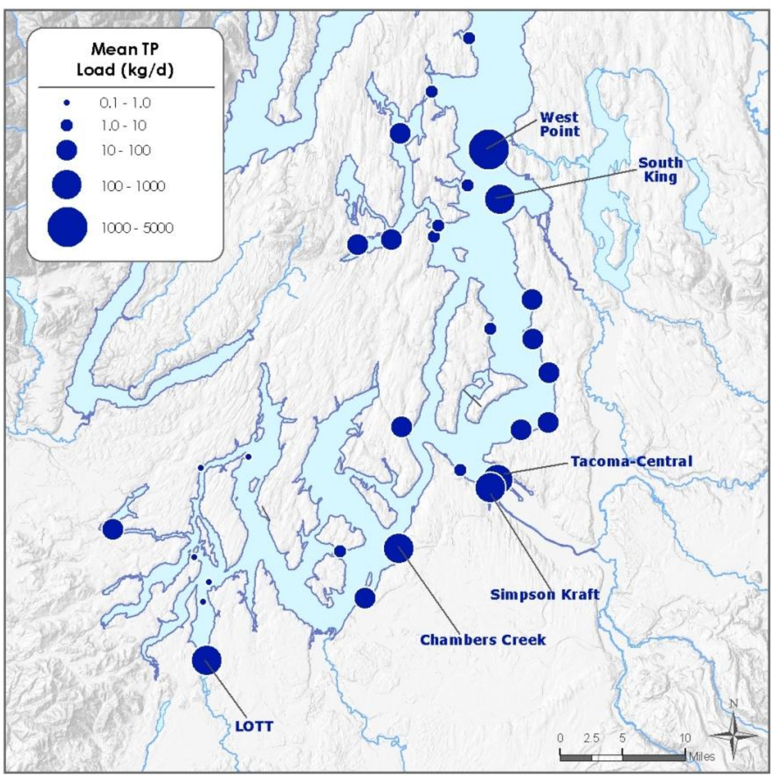


Figure G-12. Mean total phosphorus loads from WWTPs during 2006-2007.

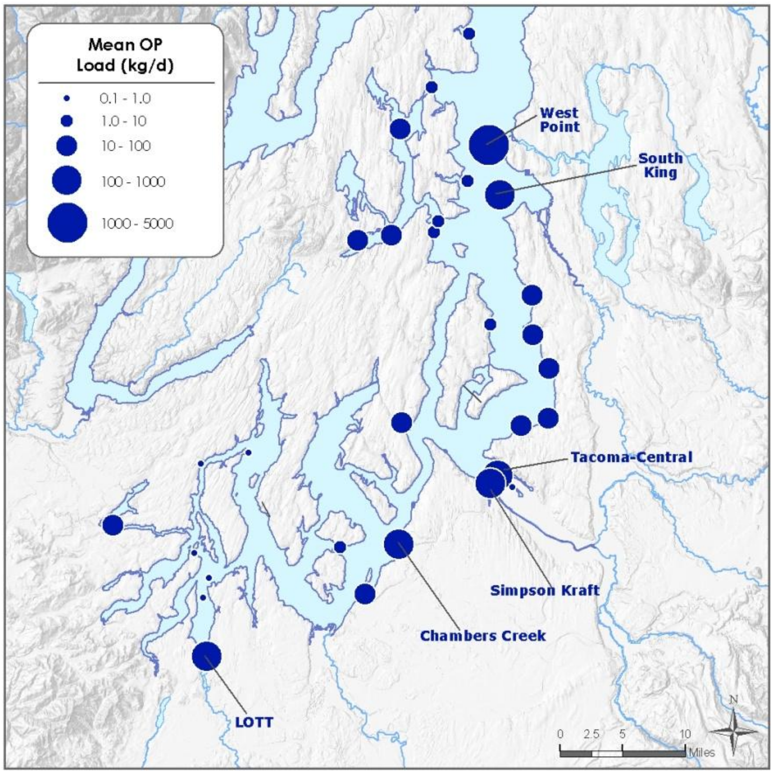


Figure G-13. Mean ortho-phosphate loads from WWTPs during 2006-2007.

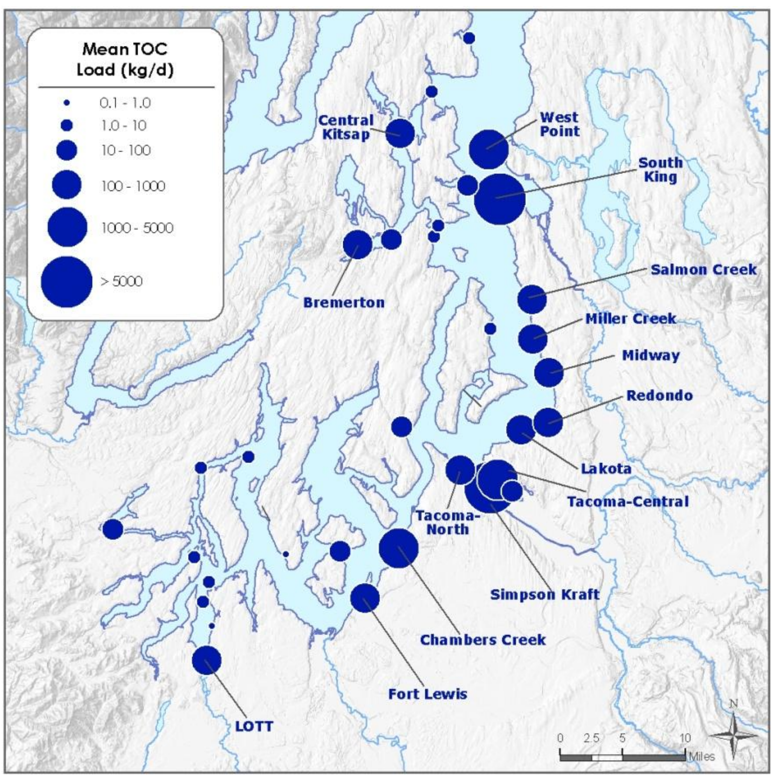


Figure G-14. Mean total organic carbon loads from WWTPs during 2006-2007.

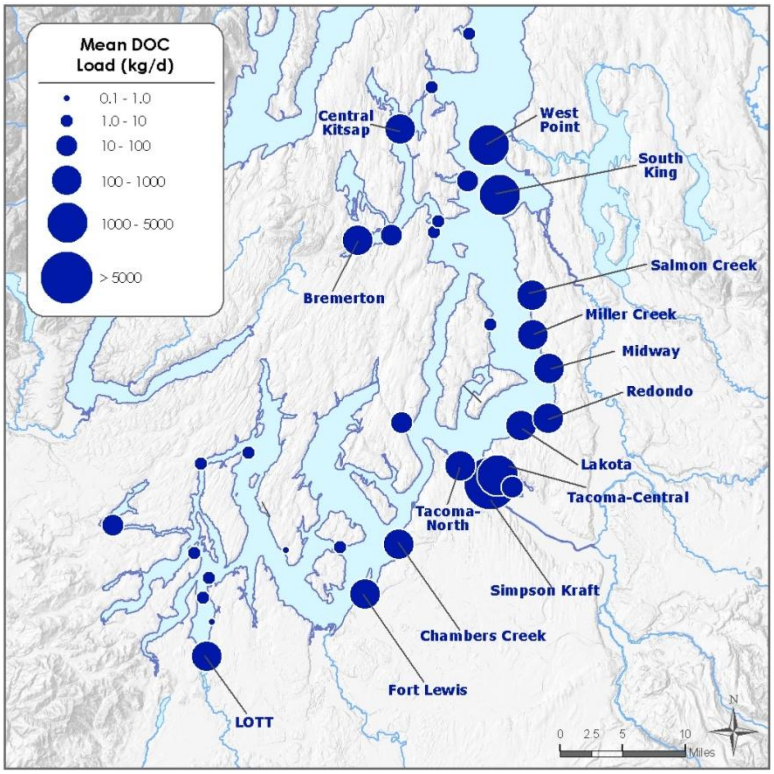


Figure G-15. Mean dissolved organic carbon loads from WWTPs during 2006-2007.

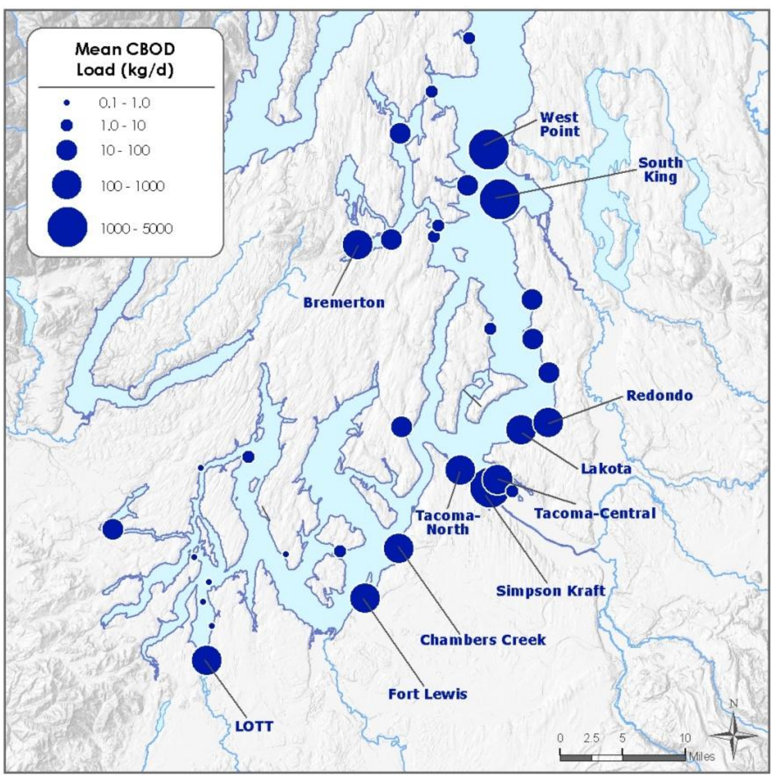


Figure G-16. Mean dissolved organic carbon loads from WWTPs during 2006-2007.

Figures G-17 through G-20 present mean monthly nitrogen, phosphorus and organic carbon loads totaled by the different regions in South and Central Puget Sound into which they drain.

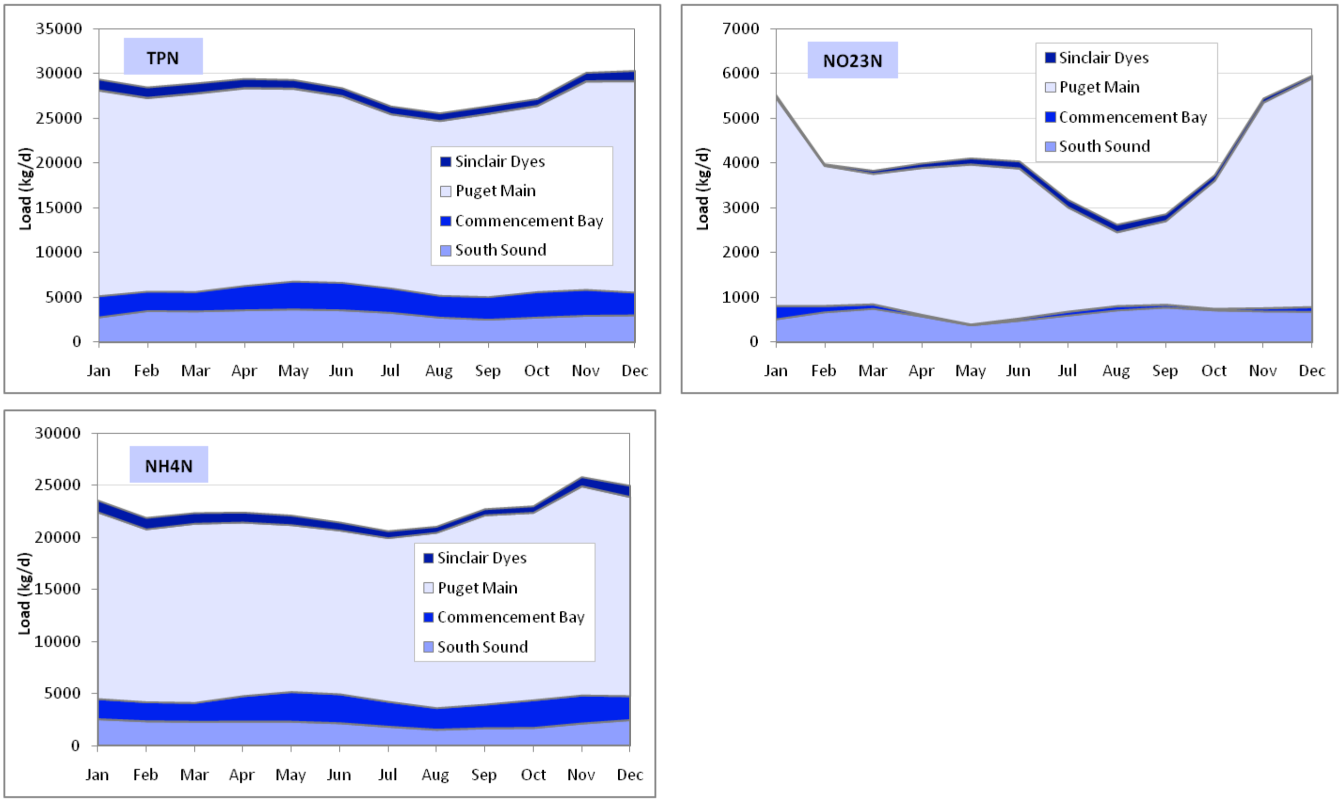


Figure G-16. Mean 2006-2007 monthly nitrogen loads from WWTPs totaled according to the regions in South and Central Puget Sound into which they drain.

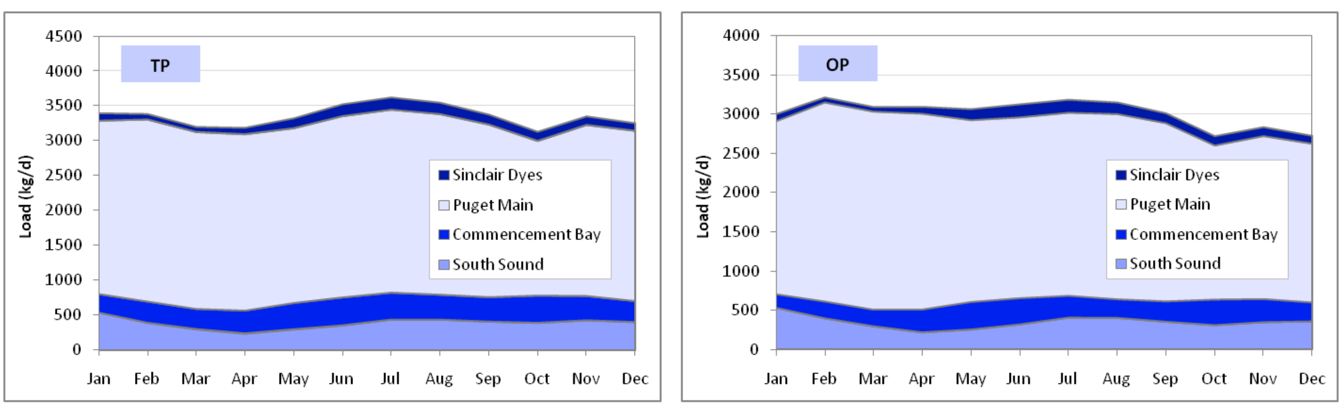
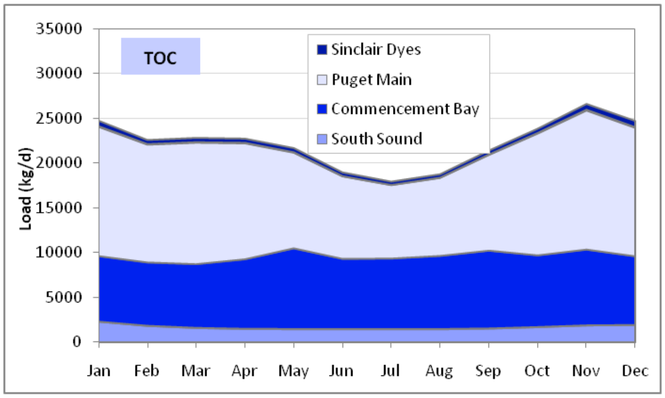


Figure G-17. Mean 2006-2007 monthly phosphorus loads from WWTPs totaled according to the regions in South and Central Puget Sound into which they drain.



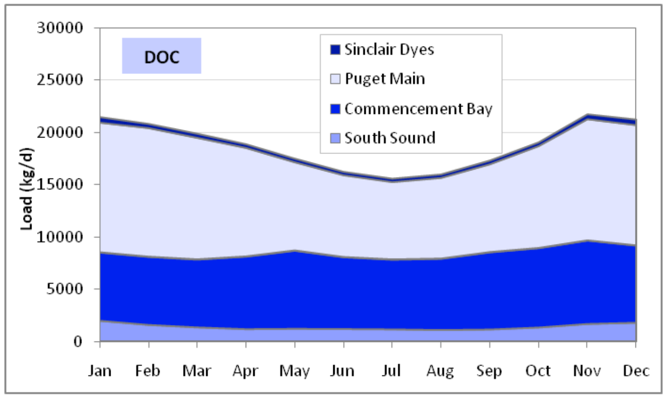


Figure G-18. Mean 2006-2007 monthly organic carbon loads from WWTPs totaled according to the regions in South and Central Puget Sound into which they drain.

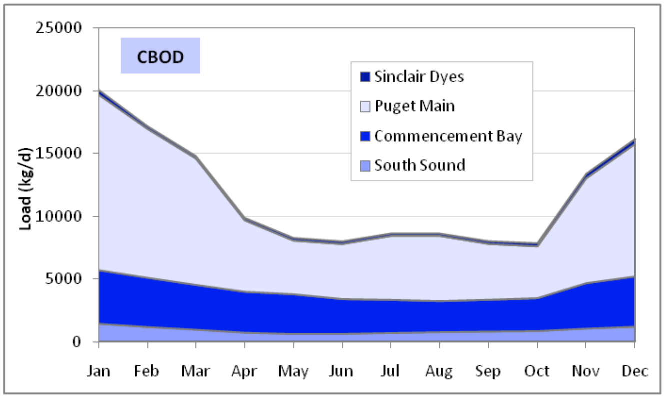


Figure G-19. Mean 2006-2007 carbonaceous biochemical oxygen demand loads from WWTPs totaled according to the regions in South and Central Puget Sound into which they drain.